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TECHNICAL MEMORANDUM NO. 4 TO FINAL PHASE I RFI/RI WORK PLAN HUMAN HEALTH RISK ASSESSMENT EXPOSURE SCENARIOS

ROCKY FLATS PLANT
SOLAR EVAPORATION PONDS
(OPERABLE UNIT NO. 4)

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant
Golden, Colorado

EG&G ROCKY FLATS, INC.
ENVIRONMENTAL RESTORATION MANAGEMENT

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EXECUTIVE SUMMARY

This Technical Memorandum No. 4 (TM4) supports the Baseline Risk Assessment (BRA) for the Phase I Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI)/Remedial Investigation (RI) for Operable Unit No. 4 (OU4) at the Rocky Flats Plant (RFP). OU4 is considered to be equivalent to Individual Hazardous Substance Site 101 (IHSS 101). OU4 is comprised of five ponds (Ponds 207-A, 207-B North, 207-B Center, 207-B South, and 207-C), the Interceptor Trench System (ITS), and areas in the immediate vicinity of the ponds.

This TM4 presents the exposure scenarios for the Human Health Risk Assessment (HHRA) portion of the BRA for OU4. The HHRA will evaluate human health risks for onsite and offsite receptors under current and future land use conditions.

The RFI/RI is performed pursuant to an Interagency Agreement (IAG) among the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the Colorado Department of Health (CDH) dated January 22, 1991 (DOE 1991a). As required by the IAG, a Phase I RFI/RI will characterize source materials and soils at OU4. Through subsequent discussions with CDH, it has been directed that the HHRA for the Phase I RFI/RI for OU4 include air pathway analyses. A subsequent Phase II RFI/RI will investigate the nature and extent of surface water, leachate, biota and groundwater contamination and evaluate potential contamination migration pathways.

The scope of this technical memorandum is limited to the identification of:

- Exposure pathways and associated intake routes and parameters for Phase I RFI/RI characterized source materials and soil within OU4; and

- Current and future human exposure scenarios for characterized source materials and soil within OU4.

Because the nature and extent of surface water, leachate, biota and groundwater contamination will not be investigated until the Phase II RFI/RI process, this technical memorandum addresses only direct (e.g., contact) and upward (e.g., wind suspension) exposure pathways associated with Phase I RFI/RI characterized source materials and soil. These source and soil materials will be used as input to environmental exposure models in order to assess risks to human health. Subsequent technical memoranda and human health risk analyses will be prepared as part of the Phase II RFI/RI process for OU4.

The objectives of this technical memorandum were to identify (1) complete exposure pathways by which chemicals may be transported from Phase I RFI/RFI identified sources to human exposure points, (2) associated human receptor populations that may be exposed to the identified chemicals, (3) the route(s) of chemical intake, and (4) intake parameters for each contaminated medium (e.g., soil). Chemical intakes have not been quantified. The magnitude of exposure is dependent on the chemical concentration at the exposure points, which will be estimated based on the analytical results of the Phase I RFI/RI and exposure assessment modeling, as appropriate. The exposure assessment focuses on media (e.g., soil) that potentially contain chemicals related to Phase I RFI/RI identified sources and associated exposure pathways, potential receptors, exposure points, and factors for potential human intake of impacted media.

A conceptual site model (CSM) of potential human exposure pathways was developed to provide a schematic representation of the chemical source areas, chemical release mechanisms, environmental transport media, potential human intake and exposure routes, and potential human receptors. The purpose of the CSM is to provide a framework for problem definition, identify exposure pathways that may result in human health risks, indicate data gaps, and aid in identifying appropriate remediation measures. Chemical release mechanisms, environmental transport media, and potential human intake and exposure routes to the contaminated site soil were identified for each potential receptor.

Current onsite workers, current offsite residents, hypothetical future onsite workers, hypothetical future onsite ecological researchers, hypothetical future onsite construction workers, and hypothetical future onsite residents are included among the receptor scenarios to be quantitatively evaluated on the basis of their credibility and representative or bounding exposure potential. While a future hypothetical onsite resident has been shown to be improbable, this exposure scenario has been retained for quantitative evaluation so that the full range of risks can be examined by the regulatory agencies. Exposure points were selected for the current offsite resident on the basis of proximity to the plant site and the predominant wind direction. The hypothetical future onsite resident, worker, ecological researcher, and construction worker are all located within the boundaries of OU4. While the hypothetical future onsite worker is a credible exposure scenario, this receptor category is more likely to have an exposure location within the existing developed area of the plant site because of its existing infrastructure of facilities and utilities. Complete human health exposure pathways to be evaluated as part of the HHRA for OU4 are:

<u>Current Offsite Resident</u>

- Inhalation of airborne particulates;
- Soil ingestion following airborne deposition of particulates on residential soil;
- Dermal contact with organic compounds in soil, following airborne deposition of particulates; and
- Ingestion of vegetables following surface deposition of particulates

<u>Hypothetical Future Onsite Worker</u>

- Inhalation of airborne particulates;
- Incidental soil ingestion;
- Direct dermal contact with organic compounds in soil; and
- Groundshine (external radiation) (direct contact).

<u>Hypothetical Future Onsite Ecological Worker</u>

- Inhalation of airborne particulates;
- Incidental soil ingestion;
- Direct dermal contact with organic compounds in soil; and
- Groundshine (direct contact).

<u>Hypothetical Future Onsite Construction Worker</u>

- Inhalation of and airborne particulates;

- Incidental soil ingestion;
- Direct dermal contact with organic compounds in soil; and
- Groundshine (direct contact).

Hypothetical Future Onsite Resident

- Inhalation of airborne particulates;
- Ingestion of homegrown vegetables (surface deposition of particulates and root uptake of site-related chemicals);
- Incidental soil ingestion;
- Direct dermal contact with organic compounds in soil; and
- Groundshine (direct contact).

Intakes and exposures were estimated using reasonable estimates of body weight, inhalation volume, ingestion rates, soil or food matrix effects, and frequency and duration of exposure. Intakes and exposures will be estimated for reasonable maximum exposure (RME) conditions. The RME was estimated by selecting values for exposure that can reasonably be expected to occur at the site. Overall, exposure parameter values were employed which would result in the derivation of exposure levels that err on the side of over- , rather than underestimation. The intake and exposure parameters to be used in the HHRA for each of the exposure scenarios indicated above are presented in Section 5.0 of this technical memorandum.

1.0 INTRODUCTION

This Technical Memorandum No. 4 (TM4) supports the Baseline Risk Assessment (BRA) for the Phase I Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI)/Remedial Investigation (RI) for Operable Unit No. 4 (OU4) at Rocky Flats Plant (RFP). OU4 consists of the Solar Evaporation Ponds (Solar Ponds) Waste Management Unit which is equivalent to Individual Hazardous Substance Site 101 (IHSS 101). OU4 is comprised of five ponds:

- Pond 207-A;
- Pond 207-B North;
- Pond 207-B Center;
- Pond 207-B South; and
- Pond 207-C.

Also included within the OU4 boundary are the Original Pond, the Interceptor Trench System (ITS) and areas in the immediate vicinity of the ponds.

The BRA is comprised of a Human Health Risk Assessment (HHRA) and an environmental evaluation. This memorandum presents the exposure assessment approach for the HHRA portion of the BRA for OU4. The HHRA will evaluate human health risks for onsite and offsite receptors under current and future land use conditions.

The RFI/RI is performed pursuant to the Interagency Agreement (IAG) among the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the Colorado Department of Health (CDH) dated January 22, 1991 (DOE 1991a). As required by the IAG, a Phase I RFI/RI will characterize source materials and soils at OU4. Through subsequent discussions with CDH, it has been directed that the HHRA for the Phase I RFI/RI for OU4 include air pathway analyses. A subsequent Phase II RFI/RI will investigate the nature and extent of surface water, leachate, biota and groundwater contamination and evaluate potential contamination migration pathways.

1.1 OBJECTIVES

The objectives of this technical memorandum are to identify (1) complete exposure pathways by which chemicals may be transported from Phase I RFI/RFI identified sources to human exposure points, (2) associated human receptor populations that may be exposed to the identified chemicals, (3) the route(s) of chemical intake, and (4) intake parameters for each contaminated medium (e.g., soil). Chemical intakes have not been quantified. The magnitude of exposure is dependent on the chemical concentration at the exposure points, which will be estimated based on the analytical results of the Phase I RFI/RI and fate and transport modeling, as appropriate. The exposure assessment focuses on media (e.g., soil) that potentially contain chemicals related to Phase I RFI/RI identified sources and associated exposure pathways, potential receptors, exposure points, and factors for potential human intake of impacted media.

1.2 SCOPE

The scope of this technical memorandum is limited to the identification of:

- Exposure pathways and associated intake routes and parameters for Phase I RFI/RI characterized source materials and soil within OU4; and
- Current and future human exposure scenarios for characterized source materials and soil and residual pond sediment within OU4.

Because the nature and extent of surface water, leachate, biota and groundwater contamination will not be investigated until the Phase II RFI/RI process, this technical memorandum addresses only direct (e.g., contact) and upward (e.g., wind suspension) exposure pathways associated with Phase I RFI/RI characterized source materials and soil. Subsequent technical memoranda and human risk analyses will be prepared as part of the Phase II RFI/RI process for OU4.

Potential scenarios were identified according to the EPA concept of reasonable maximum exposure (RME), defined as the highest exposure reasonably expected to occur at a site (EPA 1989b). The term "potential" is used to mean "a reasonable chance of occurrence within the context of the reasonable maximum exposure scenario" (EPA 1990). Using this approach, potential exposures are evaluated in Section 4.0 using a conceptual site model

(CSM). In the CSM, the likelihood of an exposure pathway occurring is classified as complete and incomplete. All potentially complete exposure pathways, regardless of the relative significance or insignificance of exposure pathways, are designated on the CSM as complete exposure pathways. Quantitatively addressing potentially complete exposure pathways will provide for risk estimates that are conservative and do not underestimate actual risks.

This technical memorandum is organized as follows: Section 2.0, Site Description, describes site characteristics that potentially impact human exposures. Section 3.0, Potentially Exposed Receptor Populations, identifies the populations that may be exposed to chemicals originating from identified site-related sources. Land uses and exposure scenarios that are most likely to occur, given the site-specific conditions, are identified for quantitative assessment in the HHRA. Section 4.0, Exposure Pathways, discusses the potential release and transport of chemicals from the site, and identifies exposure pathways to be evaluated in the HHRA using a conceptual site model. Section 5.0, Estimating Chemical Intakes, describes the methodology used to approximate the intake of chemicals in various media and identifies chemical intake factors for the calculation of chemical intake by human receptors. Section 6.0 lists the references cited throughout this document.

2.0 SITE DESCRIPTION

A brief description of the OU4 history, physical setting, meteorology, geology, hydrology, and ecology is presented in this section. Such information was derived primarily from the Phase I RFI/RI Work Plan for OU4 (DOE 1991b). It should be noted that the results from the implementation of the Work Plan and sampling and analysis will likely provide additional information regarding the site description. Such information will be incorporated into this section when such data become available.

2.1 LOCATION AND PLANT HISTORY

RFP is located on approximately 6,550 acres of federally owned land in northern Jefferson County, Colorado, approximately 16 miles northwest of Denver (Figure 2-1). Surrounding communities include Boulder, Broomfield, Westminster, and Arvada, which are located less than 10 miles to the northwest, north, northeast, and southeast, respectively. RFP includes an industrial complex of approximately 400 acres known as the protected area (PA), surrounded by a buffer zone of approximately 6,150 acres. A general description of RFP is presented in this section. For a more detailed description, please refer to the Phase I RFI/RI Work Plan for OU4 (DOE 1991b).

RFP's historical mission was to produce metal components for nuclear weapons. These components were fabricated from plutonium, uranium, and nonradioactive metals and shipped elsewhere for final assembly. When a nuclear weapon is determined to be obsolete, components of these weapons fabricated at RFP are returned for special processing to recover plutonium. Other activities at RFP have included research and development in metallurgy, machining, nondestructive testing, coatings, remote engineering, chemistry, and physics. RFP is currently performing environmental restoration activities and transition planning for decontamination and decommissioning.

2.2 HISTORY OF OU4

The Solar Ponds are located in the central portion of the RFP on the northeast side of the PA. Figure 2-2 illustrates the locations of the five ponds, the Original Pond, the ITS, and adjacent areas within the OU4 boundary. The Solar Ponds were constructed primarily to store and treat low-level radioactive wastes containing high nitrates, and neutralized acidic wastes containing aluminum hydroxide. In addition, these ponds have received wastes such as sanitary sewage sludge, lithium metal, sodium nitrate, ferric chloride, lithium chloride, sulfuric acid, ammonium persulfates, hydrochloric acid, nitric acid, hexavalent chromium and cyanide solutions.

2.3 PHYSICAL SETTING

The natural environment of RFP and vicinity is influenced primarily by its proximity to the Front Range of the Southern Rocky Mountains. RFP is located less than 2 miles east of the north-south trending Front Range and approximately 16 miles east of the Continental Divide. A more detailed description of the Colorado Piedmont can be found in the Phase I RFI/RI Work Plan for OU4 (DOE 1991b).

2.4 METEOROLOGY

The Phase I RFI/RI Work Plan for OU4 provides a detailed description of site meteorology (DOE 1991b). The region has a highly continental, semi-arid climate. Mean annual precipitation of the RFP vicinity is approximately 15 inches. More than half of this total occurs as snowfall, which averages approximately 85 inches per year. Approximately 40 percent of the annual precipitation occurs in the spring. The relative humidity annual average is approximately 50 percent. Annual free-water evaporation is approximately 45 inches (DOE 1992). The 1990 wind rose for RFP is shown in Figure 2-3. Mean wind speed for 1990 was 4.0 m/sec. The frequency of occurrence of atmospheric stability during 1990, in terms of Pasquill stability classes, was: 50.1 percent for neutral stability classes (Class D), 42.5 percent for stable classes (Class E and F), and 7.37 percent for unstable classes (Class A, B, and C).

2.5 GEOLOGY

The description of the geology in the vicinity of OU4 is derived from previous studies performed at the site. A more detailed description of the site geology can be found in the Phase I RFI/RI Work Plan for OU4 (DOE 1991b). Much of the information in the Work

Plan has been summarized from the Solar Evaporation Ponds Closure Plan (Rockwell International, 1988), the 1989 drilling program performed by Weston, EG&G Rocky Flats Summary of Field Investigations and EG&G Rocky Flats Draft Final Geologic Characterization Report (EG&G 1991c).

2.5.1 Surficial Geology

Four distinct surficial deposits of Quaternary age are present in the vicinity of OU4: Rocky Flats Alluvium, colluvium, valley-fill alluvium, and artificial fill or disturbed ground. These surficial deposits unconformably overlie the bedrock units. Rocky Flats Alluvium caps the interfluves north and south of the unnamed tributary to North Walnut Creek. Colluvium covers the hillsides down to the drainage. Valley-fill alluvium is present along the channel of the unnamed tributary. The erosional surface on which the alluvium was deposited slopes gently eastward, truncating the Arapahoe and Laramie Formations. Most of the Solar Ponds area has been disturbed by construction of the ponds and the ITS; therefore, artificial fill or disturbed surficial materials are present near the Solar Ponds area.

2.5.2 Bedrock Geology

The Upper Cretaceous Arapahoe unconformably underlies surficial materials in the vicinity of the Solar Ponds area. The Arapahoe Formation is composed primarily of claystones and silty claystones that are very similar lithologically to those in the underlying Laramie Formation.

2.6 HYDROLOGY

2.6.1 Groundwater

According to the Phase I RFI/RI Work Plan for OU4, groundwater in the area of the Solar Ponds flows east (DOE 1991b). Flow in the unconsolidated material follows the contact with the Arapahoe Formation claystones. Groundwater flow in the Solar Ponds area is influenced by recharge of precipitation, leakage from the Solar Ponds and drainage into the ITS. North of the Solar Ponds, the ITS drains groundwater from the alluvial materials creating an area of unsaturation.

2.7 ECOLOGY

A detailed description of the site ecology is presented in the Phase I RFI/RI Work Plan for OU4 (DOE 1991b). The results of sampling and analysis and the ecological evaluation may provide additional information regarding the site ecology.

2.7.1 Terrestrial Ecosystems

The terrestrial ecosystems are highly modified and in the first stages of revegetation by plants and invasion by smaller animals. Weedy vegetation has established on and around the ponds on bare soil, in adjacent level construction fill and in cracks in liners. The fill slope to the north of the ponds has a grass/weed vegetation with small marshy areas around two seeps. Arthropods and other invertebrates were observed on plants, and birds occasionally visit the site. Small mammals such as deermice are expected. Cottontails were seen and scat from either a fox or a coyote was observed. The study area contains small seeps and marshy areas. Aquatic ecosystems are lacking on the OU4 study area which is at the head of a drainage and there are no streams or natural bodies of water. The ponds cannot be considered as aquatic ecosystems due to use and management practices and the lack of viable aquatic organisms and food webs. Algae mats grow seasonally on the ponds and were observed on Pond 207B-North during the site visit in September 1991. The areas north and east of the ponds are the drainages of Walnut Creek which include both terrestrial and aquatic ecosystems (DOE 1993).

3.0 POTENTIALLY EXPOSED RECEPTOR POPULATIONS

The "*1989 Population, Economic, and Land Use Data for Rocky Flats Plant*" (DOE 1990) was used to characterize land use and population distributions around the plant site. This study encompassed an area with a radius of 50 miles from the center of RFP and included all or part of 14 counties and 72 incorporated cities, with a 1989 combined population of 2,206,550. The study projected populations through the year 2010.

3.1 DEMOGRAPHICS

RFP is located on a 6,550-acre parcel of federally owned land in a rural area of Jefferson County, approximately 16 miles northwest of Denver and 10 miles south of Boulder. The plant facility is located near the center of the parcel and is surrounded by a buffer zone of approximately 6,150 acres.

Two general receptor population groups can be identified for the RFP, namely, the population base located "near" to the RFP and the population base located "distant" from the RFP (i.e., located farther than two-mile radius from the RFP). The population located near the RFP inhabits land which is sparsely or not populated. Projections for population growth in these "near" and "distant" areas indicate that the growth will continue with the same general trends whereby the near population areas will remain as sparsely populated regions and the far population areas will undergo population increases.

The area west of RFP is mountainous, sparsely populated, and primarily government-owned. The area east of RFP is generally a high, semi-arid plain, densely populated, and privately owned. Most of the population included in the DOE study is located within 30 miles of RFP, primarily in the Denver metropolitan area to the east and southeast.

Most of the development near RFP has occurred since the plant was built, with future development expected to continue (DOE 1992). Approximately 316,000 people reside within a 10-mile radius. The most significant development is located to the southeast, in the cities of Westminster, Arvada, and Wheat Ridge. The cities of Boulder to the northwest:

Broomfield, Lafayette, and Louisville to the northeast; and Golden to the south also contain significant developments within this 10-mile radius (DOE 1992).

Figure 3-1 (taken from DOE 1990) illustrates the distribution of the residential population within a 5-mile radius of RFP in 1989. The projected residential population for the year 2010 is illustrated in Figure 3-2 (DOE 1990). Sectors 1 and 2 represent land within the RFP boundary and therefore are relevant to onsite scenarios. Sectors 1 and 2 also provide information relevant to the near population area for the RFP. The current population for Sectors 1 and 2 is zero. Sectors 3, 4, and 5 mostly include property outside the RFP boundary and thus are relevant to offsite scenarios, and the distant population area for the RFP. Radial Segments D through I, which lie in the predominant downwind directions from OU4, represent the primary areas relevant to upward exposure pathways. The total population for Sector 3 is 24, with Sectors 4 and 5 providing the primary contribution (population = 8,172) to the total population figure for Sectors 3, 4, and 5.

The 1989 and projected 2010 population data shown in Figures 3-1 and 3-2 are summarized in Table 3-1. The information presented in Table 3-1 indicates that zero population growth is projected in the next 18 years for the near population areas immediately adjacent to the RFP boundary (Sectors 1 through 3). The potential exists that the population may grow in sectors which border the RFP. An increase in population and the number of households is predicted for the three- to six-mile radius areas around the RFP boundary (Figures 3-1 and 3-2 and Table 3-1).

The school closest to RFP is Witt Elementary School, approximately 2.7 miles east of the buffer zone (EG&G 1991b). All other sensitive subpopulation facilities (e.g., hospitals and nursing homes) are located beyond the 5-mile radius from the center of RFP. Ninety-three schools, eight nursing homes, and four hospitals occur within a 10-mile radius of RFP, but all are outside the five-mile radius (DOE 1992).

The nearest drinking water supply is Great Western Reservoir, located approximately 2.3 miles east of the center of RFP. The continued use of Great Western as a drinking water source is limited. The City of Broomfield has, with DOE's assistance, set into motion a plan to obtain drinking water for the municipality from other sources that are distal from RFP. The current plan is for the alternative water supply to be in place and functioning by 1997. The City of Broomfield operates a water treatment facility immediately downstream from Great Western Reservoir. This facility supplies drinking water to approximately 28,000 persons. Standley Lake Park, a recreational area and a drinking water supply for the cities of Thornton, Northglenn, Westminster, and Federal Heights, is located 3.5 miles to the southeast of RFP. After 1997, Standley Lake will be the closest water supply with respect to the location of OU4. However, Standley Lake does *not* drain the watershed to which OU4 supplies recharge. From Standley Lake, water is piped to each city's water treatment facility. Boating, picnicking, and limited overnight camping are permitted at Standley Lake Park.

3.2 OFFSITE LAND USE

3.2.1 Current

Current land use in the area surrounding RFP is shown in Figures 3-3 and 3-4. Table 3-2 is a summary of land use corresponding to the Jefferson County Land Use Map. In general, current land use surrounding RFP includes open space (recreational), agricultural, residential, and commercial/industrial. Northeastern Jefferson County, including RFP, is one of the most concentrated areas of industrial development in the Denver metropolitan area (Jefferson County 1989).

Based on observation, current land use in the area relevant to the OU4 exposure scenarios (immediately southeast of RFP and OU4) includes all of the uses mentioned above. Predominant uses appear to be open space, single-family detached dwellings, and horse-boarding operations. Two small cattle herds (approximately 10 to 20 cattle in each) were observed: one to the southeast, where 96th Avenue turns into Alkire and crosses Woman Creek; and one to the east of RFP, between Alkire and Simms Streets and north of 100th Avenue. Industrial facilities within the relevant area, include the TOSCO laboratory, Great

Western Inorganics Plant, and Frontier Forest Products (EG&G 1991b). All are located to the south, along Colorado Highway 72.

3.2.2 Future

Future land use generally follows existing patterns. Jefferson County (1989) developed a baseline profile of growth and land use in the area as part of a socioeconomic study of its northeastern area (*Northeast Community Profile*). As a result of this study, Jefferson County expects that industrial land uses will continue to dominate the northeastern portion of the county. Along with the increase in industrial development, the county expects income and employment growth to increase dramatically, while household and population growth is expected to increase only moderately. In other words, with industrial growth, employment opportunities are expected to increase; yet, as the land is developed for industry, the availability of land for residential development decreases. As a result, household and population growth will be limited.

Industrial and commercial development of the area is attractive to businesses and developers because of (1) the availability of undeveloped, lower-cost lands, and (2) the lower taxes associated with locating in an unincorporated portion of the county.

Both the proposed construction of highway W-470 and its alignment are uncertain. Near-term (5 years) development of the highway is unlikely. Proposed alignments have included skirting either the southern and eastern or western and northern boundaries of RFP. Commercial growth, particularly light industries and office parks, would be expected to occur along the highway (Jefferson County 1989).

Residential development is not as attractive as industrial development of the area for several reasons, including the potential alignment of W-470, the proximity to Jefferson County Airport, and the proximity to RFP. The decreased desirability of living near a major highway or an airport, for traffic and noise reasons, is a deterrent to residential development. The proximity of RFP and the general industrial nature of the area also decreases the desirability of housing in the area.

Future land use in the area is the topic of *The North Plains Community Plan* (Jefferson County 1990). The plan is intended to serve as a guide to the county and cities to achieve compatible land use and development decisions, regardless of the jurisdiction. It was developed cooperatively by representatives of Jefferson County and five communities (Arvada, Broomfield, Golden, Superior, and Westminster) as well as a variety of interest groups, including homeowners, businesses, builders/developers, environmentalists, and special districts. The plan identifies RFP and the Jefferson County Airport as constraints to future residential development in the area and recommends office and light industrial development. It further identifies the acquisition of lands for open-space uses as a high priority for the area and recommends that large amounts of undeveloped land be provided for this purpose (Jefferson County 1990).

The North Plains Community Development Plan Study Area Summary Map (Figure 3-5) and the Jefferson Center Comprehensive Development Plan (Figure 3-6) show that the predominant future land uses south and southeast of RFP will consist of commercial, industrial, and office space. Directly to the east, land use is expected to remain open space and agricultural/vacant. Residential development is projected to occur farther from RFP than these other uses. This planning is consistent with the zero projected residential growth rate in the next 18 years for areas immediately adjacent to the RFP (DOE 1990). Projected industrial growth will place additional demands on finite resources such as water and land and will probably result in increasing costs for these resources. At some point in the future, these increasing costs are expected to make agricultural use of the land impracticable.

North of RFP in Boulder County, the predominant land uses include open space, parkland, and industrial development, as shown in Figure 3-4. Two areas adjacent to RFP have been annexed by the towns of Broomfield and Superior. These two communities have participated in the Jefferson County cooperative planning process and are planning business, industrial, and mixed-land uses for the area (City of Broomfield 1990, Jefferson County 1990, Boulder County 1991).

The information presented above indicates that current land use in the immediate vicinity of RFP is primarily commercial/industrial and that such land use will continue into the future. It is likely that the potential for residential development in this area will be impeded by the growth of business and industry that is expected to occur, and potentially by the presentation of open space.

3.3 ONSITE LAND USE

3.3.1 Current

Current activities within OU4 include environmental investigations, maintenance activities and routine security surveillance. Access into the OU4 area is limited to individuals with appropriate security clearance credentials. The secured area is fenced and security personnel are on duty 24 hours per day. Thus, the potential for trespassers or other non-authorized individuals to enter into the area is virtually non-existent. Each of the ponds are roped off and signs are posted to indicated that the ponds are radiologically controlled areas; that consumables are not allowed in the areas; and that a radiologic work permit, a dosimetry badge, and appropriate safety glasses are required for entry.

3.3.2 Future

Future plans for RFP activities are discussed in the Nuclear Weapons Complex Reconfiguration Study. The two preferred reconfiguration options in the study include relocation of RFP functions (DOE 1992). Future land-use alternatives are discussed in the RFP *Final Environmental Impact Statement* (EIS) (DOE 1980). Four alternatives are addressed in the document, including the no-action alternative. These alternatives, which may be subject to change, are summarized below (DOE 1992):

- The no-action alternative involves completion of nuclear production upgrades, maintenance of production standby, and compliance with the IAG environmental restoration (ER) commitments;

- Alternative 1 involves nuclear production at reduced levels, compliance with IAG ER commitments, and placement of surplus facilities into safe storage. This alternative is no longer considered viable, owing to the recent decision to implement D&D at RFP;

- Alternative 2 allows nuclear production at up to 1989 levels, increased non-nuclear production, placement of surplus facilities into safe storage, and completion of ER by 2020. This alternative is no longer considered viable, for the same reason as Alternative 1; and

- Alternative 3 involves transition to no production of nuclear or non-nuclear components, completion of ER by 2020, D&D of selected facilities, and placement of other facilities into safe storage.

Use of onsite production facilities by private industry is planned for the future at RFP, according to a June 12, 1992, speech by Secretary of Energy James Watkins. Watkins characterized RFP as an attractive site for manufacturers and other businesses (Denver Post 1992). Private industry could relocate to existing buildings and use existing equipment at RFP, after necessary decontamination is complete (Boulder Daily Camera 1992). One organization working to achieve this objective is the Rocky Flats Local Impacts Initiative (RFLII). This group is comprised of representatives from local businesses and government agencies and has been formed to develop a strategy to transform future changes at RFP into economic, socioeconomic, educational, land use, environmental, and infrastructural advantages. One of this group's goals is to work with the DOE and local economic development agencies to identify and attract businesses to occupy existing buildings at RFP (RFLII 1992).

Future land use of the RFP Site will be also impacted as result of the DOE's Rocky Flats Plant Mission Transition Management Plan (Transition Plan, DOE, 1992). The Transition Plan indicates that the future plant site uses will change to include alternative uses. Additionally, the Transition Plan discusses economic development of the plant site. The DOE Rocky Flats Office opened an Economic Development Office in July 1992. The purpose of this Office is to identify and implement opportunities for economic development at the RFP with the ultimate goal of retaining and using the unique technologies and capabilities of the RFP and its skilled workforce. Commercialization of any facility at the plant will be coordinated closely with the community through the Rocky Flats Local Impacts Initiative (DOE, 1992b).

Though still in its preliminary stages of development, the Transition Plan indicates that the alternative uses selected for the plant site could emulate the industrial setting presently in place. As a result, in a plausible future use scenario, it is very possible that the population potentially exposed to materials at OU4, in the future will be workers producing products that employ RFPs unique technologies and capabilities.

When the Atomic Energy Commission (AEC) acquired the undeveloped land surrounding the production area, it established plans to preserve the land as open space (AEC 1972). It is plausible that the buffer zone and OU4 area will be preserved as open space. The buffer zone is being considered as a potential ecological preserve or National Environmental Research Park.

> There are at least three reasons why RFP would make an exceptional environmental research area. First, the site presents an excellent sample of a shortgrass prairie/montane ecotone... Second, it also provides an almost unique opportunity to conduct environmental research in an area which abuts a major metropolitan area... Third, ...the site has an abundance of wetlands and would be an excellent outdoor laboratory for a variety of wetland related ecological research (Knight 1992).

Ecological surveys of the buffer zone, performed as part of the RFI/RI process and for compliance with the Endangered Species Act, have indicated the high quality of habitats at RFP and the documented or potential presence of several species of special concern. Additional surveys are ongoing to identify and provide for the protection of any threatened and endangered species at the site, if necessary (EG&G 1992b). Because the buffer zone has not been impacted by commercial development for many years, progressive re-establishment of native habitats has occurred. Thus the future use of this area as an ecological reserve is reasonable and consistent with DOE policy and plans (DOE 1992). This type of use is also consistent with the Jefferson County Planning Department's recommendations for the provision of large amounts of undeveloped land in the area (Jefferson County 1990). Extensive development of the area is also unlikely owing to the historical use of RFP, the potential for conversion of the buffer zone into an ecological preserve, and the steep topography in some areas.

The limited availability of water is also a factor affecting development of the RFP area, as with all of the Denver metropolitan area. The Denver Water Board controls most of the metropolitan water supply and currently provides much of the suburban area's water. The Denver Water Board, however, is under no obligation to supply water to the suburbs, making the future supply questionable (Jefferson County 1989). The amount of industrial development expected in the area surrounding RFP will also result in competition for water. In addition, existing facilities within RFP are already served by municipal water supplies from the City of Golden, increasing the likelihood that existing structures will be targeted for use by industry and business.

In summary, considering the information presented above, future land use of OU4 will generally likely follow existing land-use patterns and will likely involve industrial/office or open-space uses.

3.4 QUALITATIVE EVALUATION OF POTENTIAL RECEPTORS

Current and future human population groups on and near the site are potential candidates for evaluation based on their likelihood of exposure to site-related chemicals of concern. EPA guidance does not require an exhaustive assessment of every potential receptor and exposure scenario (EPA 1992a). Rather, the highest potential exposures that are reasonably expected to occur (reasonable maximum exposures) should be evaluated, along with an assessment of any associated uncertainty (EPA 1989a).

The current pattern of land use and the likelihood of future land uses are summarized in Table 3-3. The probability of future land-use scenarios is defined in terms of increasing credibility, as follows: (1) improbable (unlikely to occur), (2) plausible (conceivable, though not expected), and (3) credible (believable with reasonable grounds).

Future onsite uses for agriculture and residential communities and future offsite use as an ecological reserve are classified as improbable. Future onsite agricultural uses are considered improbable because of:

- Growth pressures on water and land resources from planned offsite development, as discussed in Section 3.2.2; and

- Competition with more credible future onsite land uses (e.g., ecological reserve, industrial), as noted in Section 3.3.2.

Future onsite residential uses are classified as improbable for multiple reasons, as summarized below:

- Inconsistency with planned offsite industrial and commercial development of the area;

- Unattractiveness for residential development because of proximity to current and future industrial uses, including the RFP facilities and the Jefferson County Airport;

- Limited water resources for residential development;

- Inconsistency with proposed onsite uses for the buffer zone (e.g., ecological open space) and the current developed areas (e.g., industrial use); and

- Inconsistency with the transition and economic development plans which emphasize use of Rocky Flats unique technological facilities and skilled workforce.

Future offsite use of the immediate area surrounding RFP as an ecological reserve is designated as improbable based on:

- Projected offsite industrial and commercial development of the area; and

- Unattractiveness of the area as an ecological reserve because the native habitat has been largely disturbed by current agricultural, grazing, and development activities.

Future offsite agricultural land uses are identified as plausible (as opposed to credible) because it is believed that current agricultural areas will be phased out because of Front Range development and associated demands and increasing costs on land and water resources. Future offsite land uses for residential communities, commercial/industrial development, and recreational activities are identified in Table 3-3 as credible exposure scenarios. It is expected that the portion of the plant where buildings now exist will continue to be industrial, and the buffer zone will remain undisturbed due to the reasons outlined in Sections 3.2 and 3.3. These reasons are:

- Future offsite land use plans point toward industrial and open space usage around the plant;

- Private industry is expected to occupy the buildings in the industrial onsite areas;

- It would be advantageous to keep the buffer zone surrounding the industrialized onsite area as an ecological preserve/open space due to its unique nature; and

- Residential development is relatively unattractive, as discussed previously.

Offsite residential, commercial/industrial, and recreational exposure scenarios are considered credible in the future because they currently exist offsite.

3.5 RECEPTORS SELECTED FOR QUALITATIVE RISK ASSESSMENT

As noted in Section 3.4, exposure scenarios that are more credible are more appropriate candidates for quantitative assessment in the HHRA. Additionally, where multiple scenarios are credible, not all need be analyzed, because those scenarios having less potential exposure will be bounded by those having greater potential exposure. Scenarios having a greater potential exposure may be determined based on various factors, including exposure route, exposure frequency and duration, and contact rates. Exposure scenarios selected for quantitative evaluation and the bases for their selection are presented in Table 3-4. Current onsite workers, current offsite residents, hypothetical future onsite workers, and hypothetical future onsite ecological researchers, and hypothetical future onsite construction workers are included among the receptor scenarios to be quantitatively evaluated on the basis of their credibility and representative or bounding exposure potential. While a future hypothetical onsite resident has been shown to be improbable, this exposure scenario has also been retained for quantitative evaluation so that the full range of risks can be examined as required by the regulatory agencies. The future hypothetical onsite construction worker is evaluated in association with the development/maintenance activities which could be required to modify the site for commercial use, residential use, or for use as an ecological reserve. Each of these receptor scenarios is described in further detail below.

Exposure points for these receptors are shown in Figure 3-7. The current onsite worker and the hypothetical future onsite resident, worker, construction worker, and ecological researcher are all located within the boundaries of OU4. While the hypothetical future onsite worker is a credible exposure scenario, this receptor category is more likely to have an exposure location within the existing developed area of the plant site because of its existing infrastructure of facilities and utilities. The future hypothetical onsite resident and ecological worker may be more likely to have exposure locations which are relegated to areas in OU4 where such development is most feasible. Exposure sources will be characterized by aggregating data into two groups to characterize the Solar Ponds Area and the hillside areas as separate exposure source areas.

3.5.1 Current Onsite Worker

The human health assessment will evaluate current onsite workers who work within OU4. Such workers may include workers who are responsible for operations/maintenance of the ponds; guards and/or surveillance personnel; truck drivers and delivery personnel; and workers in the storage area for non-recyclable materials and the hazardous waste satellite collection area. Exposure data have been collected for such workers overtime. The exposure data and a preliminary analysis of the exposure data are presented in Appendices A and C.

In addition, employees use the roadway below the ponds and hillside for recreational jogging and walking. This roadway is fenced on both sides precluding joggers or runners from entering into OU4. The present Solar Ponds maintenance/operations worker was selected as the current onsite worker to be evaluated quantitatively in the human health risk assessment. The maintenance/operation worker may have the greatest potential for exposure in OU4 based upon consideration of relative exposure frequency, duration, and contact rates compared to other workers who enter into the OU4 area.

EG&G Rocky Flats Plant, Inc. Health and Safety (H&S) activities at RFP are directed by the Associate General Manager for Support Operations and supported by several divisions, including Radiological Operations, Occupational Safety, Health and Safety Area

Engineering, Industrial Hygiene, Radiological Engineering, and Occupational Health (EG&G 1990). For environmental restoration work at RFP, EG&G Rocky Flats Plant, Inc. and DOE have adopted the federal Occupational Safety and Health Administration's (OSHA) standards for hazardous-waste site workers (EG&G 1990). EG&G has superseded some of the OSHA standards with more stringent policies established by EG&G, DOE, or other governmental agencies (EG&G 1990). At RFP, H&S programs are written for everyday activities as well as specific projects. All EG&G subcontractors must prepare their own site/project-specific H&S plans and must require and enforce standards at least as stringent as those of EG&G (EG&G 1990).

Programs at RFP that support the H&S plans and programs include radiation protection, emergency response, occupational safety, vehicular and pedestrian safety, fire protection, and contractor safety (EG&G 1992c). The written programs contain the requirements and procedures to be followed to ensure a work environment that is free from exposure to chemical, physical, and biological hazards (EG&G 1992c). Workers at RFP potentially exposed to radionuclides, including those around OU4, are governed by DOE Order 5480.11 *Radiation Protection for Occupational Exposures* (DOE 1988). Order 5480.11 prescribes practices to implement DOE's policy with respect to workers at DOE facilities. This policy establishes radiation protection standards that are consistent with approved guidance to federal agencies promulgated by the Environmental Protection Agency and based on the recommendations by authoritative organizations including the National Council on Radiation Protection (NCRP) and the International council on Radiation Protection (ICRP) (DOE 1998). Order 5480.11 sets a 500 mrem/year exposure guideline for a radiation worker. Additionally, responsibility for all aspects of compliance with the programs and plans is established, and an audit program is in place to evaluate whether compliance is in effect. RFP personnel are trained in personal hygiene and safety, use of protective clothing, and emergency response procedures. The health and safety of current workers at RFP is thoroughly monitored, with required baseline, annual, and exit physical examinations. The exposure of these workers to chemicals of concern is controlled and limited by monitoring to acceptable levels and is ensured by reporting requirements. Industrial hygiene monitoring, monitoring during sampling activities in OU4 and external dosimetry data for workers employed in the Solar Ponds Area at RFP are presented in Appendices A and B. The present Solar Ponds maintenance/operations worker was selected as the current onsite worker to be evaluated on the basis of his greater potential for exposure considering exposure frequency, duration, and contact rates. Based on the analysis of the dosimetry data for the Solar Ponds workers obtained to date, the DOE's 500 mrem/year guideline for radiation worker exposure has not been exceeded.

3.5.2 Current Offsite Resident

The human health risk assessment will evaluate current offsite residents at existing locations, since the public is restricted from access to RFP. Present levels of security at the RFP include fencing, armed security patrols, and modern electronic security and surveillance systems. Fencing is posted to warn potential intruders that they are trespassing on federal property and, if caught, will be arrested. Plant security personnel report that there have been no incidents of trespassing in the buffer zone in the past seven years. Thus, even if trespassing were to occur at the RFP, it is highly unlikely that such events would occur repeatedly for the same individual.

This scenario will evaluate the reasonable maximum risk to the present residential population. Existing residential locations selected for evaluation are shown in Figure 3-7. These locations correspond to the most reasonable locations for maximum exposures based on their proximity to the site and the direction of prevailing winds. They are also expected to be representative of future residential exposures because future industrial/commercial land use plans for the area exclude the likelihood of any significant additional residential development.

Some insight into the exposure potential for offsite residents from OU 4 can be gleaned from the radiation dose assessments presented in the Rocky Flats Plant Site Environmental Report for 1991. In that report a conservative radiation dose assessment based on monitoring data from air, water, and soil sampling programs is presented. The conservatively estimated maximum individual dose from all pathways (for 1991) was 0.32 mrem (effective dose equivalent [EDE]) (EG&G, 1992). This dose, when contrasted with the ICRP and NCRP recommended standard of 100 mrem, demonstrate that RFP as a whole is well within compliance with consensus standards. An additional comparison with the estimated annual natural background individual radiation dose for the Denver Metropolitan Area of 350 mrem (EDE) indicates that the dose attributable to the RFP is less than 1/1000 of an individual's background dose (EG&G, 1992).

3.5.3 Future Onsite Worker

The human health risk assessment will evaluate future onsite workers. Based on the future industrial development plans in the area, the worker will be assumed to be an industrial or office worker. The location of this receptor is shown in Figure 3-7. As discussed in Section 3.3.2, it is expected that desirable locations for future development of commercial facilities will be in close proximity to existing structures and utilities. Thus, the most likely location of the hypothetical future onsite worker is within the currently developed area of the plant site. The exposure location for this hypothetical receptor is conservatively assumed to be within the boundaries of OU4.

It is also assumed that the future onsite worker may or may not be a "radiation worker" as defined by DOE Order 5480.11 (DOE, 1988). Thus, effective dose equivalents, computed in accordance with U.S. EPA risk assessment guidance, will be compared to the 500 mrem/year radiation worker guideline and to the 100 mrem/year guideline for exposure to members of the public (EPA, 1989a-Chapter 10, NCRP, 1987).

Based on the future industrial development plans for the area, the future onsite worker is assumed to be an industrial or office worker at an appropriate facility. This setting is likely to have extensive paved areas and well maintained landscaping. This evaluation will be performed since all future land uses point to this setting as the most probable future land use of the industrial area of RFP.

3.5.4 Future Onsite Ecological Researcher

Because the future use of onsite undeveloped areas (e.g., buffer zone) at RFP will most likely involve open space or an ecological reserve, this scenario will be evaluated for the area within OU4. The receptors in an open-space scenario would include day hikers and a research biologist/ecologist conducting area studies. Of these two potential receptors, the research biologist is likely to spend more time at the site and come in closer contact with the soils, plants, and surface water. Field work may involve kneeling or sitting on bare ground or vegetation and contacting site soils, sediments, and surface water. The day hiker would probably spend less time at the site and come in less contact with soils and surface water. Therefore, the most reasonable maximum exposure scenario in this setting is the hypothetical future ecological researcher. As with the future onsite worker, the future onsite ecological researcher may or may not be characterized as a "radiation worker" according to DOE Order 5480.11 (DOE, 1988). Effective dose equivalents will be computed for the future onsite ecological worker and compared to applicable NCRP guidelines for radiation workers and for members of the general public (EPA, 1989a; NCRP, 1987). The area applicable to this receptor is shown in Figure 3-7.

3.5.5 Future Onsite Construction Worker

A future onsite construction worker scenario will be evaluated quantitatively to represent potential exposures to workers involved in outdoor maintenance, repair, or construction activities. Potential activities for a construction worker could include trenching in site soil, installing sewer and/or other utility lines, use of machinery to bulldoze or level site soils, paving of soil surfaces, etc. It is assumed that such work would occur over a limited time period (i.e., less than seven years). The future onsite ecological researcher may or may not be considered a "radiation worker" in accordance with DOE Order 5480.11 (DOE, 1988). Effective dose equivalents will be calculated for the future onsite construction worker and compared to applicable NCRP guidelines for radiation workers and for members of the general public (EPA, 1989a; NCRP, 1987).

Construction work might result in direct contact with site soil, and with vapors or dusts from site soils. It is anticipated that the exposure duration for work at OU4 would encompass periods where the worker's employment duration may be more or less frequent, as well as times when adverse weather will prohibit access to the site.

3.5.6 Hypothetical Future Onsite Resident

The human health risk assessment will include quantification of future onsite resident exposures, though land use projections make exposures to this receptor category improbable. It is further assumed that the hypothetical future resident exposure location is within the OU4 boundaries. The future hypothetical onsite resident would be unprotected and untrained in health and safety matters. Additionally, the future onsite resident is likely to spend the greatest amount of time at or near OU4 because of its proximity to the resident's home. Consequently, the future onsite resident scenario will represent the maximum frequency, duration, and level of exposure among the receptor categories evaluated. Such hypothetical future onsite residents will thus be considered members of the public with respect to NCRP Report No. 91 and effective dose equivalent guidelines outlined in EPA guidance for risk assessment (NCRP, 1987; EPA, 1989a).

4.0 EXPOSURE PATHWAYS

This section discusses the potential release and transport of chemicals from OU4 and exposure pathways to receptor populations identified in Section 3.0.

An exposure pathway is a specific environmental route by which an individual may potentially be exposed to chemical constituents present on, or originating from, a site. An exposure pathway includes five necessary elements:

- Source of chemicals or radionuclides;
- Mechanism of chemical release;
- Environmental transport medium;
- Exposure point; and
- Human intake route.

All five elements must be present for an exposure pathway to be complete. An incomplete pathway means that no human exposure can occur. Only potentially complete and relevant pathways for the Phase I investigation will be addressed in the HHRA for OU4. An exposure pathway is considered to be potentially complete and relevant if there are potential chemical release and transport mechanisms and receptors for that pathway.

4.1 CHEMICAL RELEASE SOURCES AND TRANSPORT MEDIA

The identified site sources at OU4 are the present Ponds and contaminated soil. The Phase I HHRA will evaluate ponds solid waste and contaminated soil at these areas as the primary sources of chemical release. A description of activities conducted at OU4 is provided in Section 2.1. Environmental media that may transport chemicals of concern from OU4 to exposure points are described below in the conceptual site model.

4.2 POTENTIAL EXPOSURE SCENARIOS

Potentially exposed receptor populations selected for quantitative assessment in the baseline HHRA were characterized in Section 3.0. The following receptors were selected:

- Current onsite worker;
- Current offsite resident;
- Hypothetical future onsite worker;
- Hypothetical future onsite ecological researcher;
- Hypothetical future onsite construction worker; and
- Hypothetical future onsite resident.

The current offsite resident is evaluated under current land use conditions. The future land use scenarios assume no action takes place at OU4 and estimate exposure for future receptor populations under this condition.

4.3 EXPOSURE POINTS

An exposure point is a specific location where human receptors may come in contact with site-related chemicals. Exposure points are selected so that reasonable maximum exposures will be quantitatively evaluated. Evaluation of receptor risks at these exposure points will bound the risks for receptors at other exposure points not selected for quantitative evaluation. The following exposure points were selected based on reasonable maximum estimates of risk. The exposure point locations are shown in Figure 3-7.

Current Scenario

- Occupational Receptor. Present ponds worker within the boundary of OU4; and
- Residential receptor. Nearest residence to RFP (located at the southeastern corner of the RFP property boundary) and nearest residence in the predominant wind direction.

Future Scenario

- Occupational receptor. Hypothetical onsite worker within the boundary of OU4;
- Ecological researcher. Hypothetical onsite ecological researcher within the boundary of OU4;

- Construction Receptor. Hypothetical onsite construction worker within the boundary of OU4; and

- Residential receptor. Hypothetical onsite resident within the boundary of OU4.

4.4 HUMAN UPTAKE MECHANISMS

A human uptake mechanism is the route by which a chemical is absorbed by the receptor. The four basic human uptake mechanisms are dermal absorption, inhalation, ingestion, and, if gamma-producing radionuclides are present, external exposures. Exposure pathways that potentially lead to these mechanisms include inhalation of volatile organic compounds (VOCs) and airborne particulates, ingestion of soil, and dermal contact with soil or surface water. These uptake mechanisms are described further in Section 5.0.

Dermal absorption of metals from contact with soil is not considered by EPA to be a significant uptake route. The Preliminary Risk Assessment for Leadville, Colorado, prepared by EPA Region VIII, states:

> Metals bind strongly to soil greatly reducing their bioavailability. Through complex processes, most metals form strong, stable bonds with other soil constituents that reduce the available concentration of a dissolved metal. In addition, due to polarity and solubility, metals are not absorbed well across the skin. Therefore, relative to other exposure routes, dermal absorption is expected to be inconsequential (EPA 1989b). Additionally, according to recent EPA guidance (EPA 1992b), dermal exposures to contaminants in soils are significant relative to oral or inhalation exposures, only when the skin surface area available for contact is significant, and only for "chemicals which have a percent absorbed exceeding about 10%." This same guidance says that the dermal absorption percentage for metal (based on cadmium) is on the order of 0.1% to 1.%, thus showing that the magnitude of exposure to metals at the site via dermal absorption will not be significant relative to other routes of exposure. Therefore, dermal exposure to metals will not be evaluated in this assessment.

For radionuclides, EPA guidance states that "dermal uptake is generally not an important route of uptake for radionuclides, which have small dermal permeability constants" (EPA 1989b). Dermal contact with soil will be assessed quantitatively only if results of OU4 Phase I sampling programs demonstrate the presence of organic chemicals of concern in surface soils at concentrations exceeding background levels.

The potential for uptake of VOCs potentially emitted from OU4 soil or pond sediment is not a significant uptake pathway. Although VOCs have been found in soil and sediment samples from OU4, the concentrations of the VOCs and the frequency of detection of the VOCs has been minimal. In many cases, the VOC concentrations were reported as estimated values which were lower than the laboratory detection limits. In addition, potential blank contamination was also reported for the common laboratory contaminants. Otherwise, the VOCs were found at very low concentrations or at the laboratory detection limit (DOE, 1991b).

An identification of the soil VOC concentration associated with unacceptable exposure, risk and/or hazard level is provided in Appendix C. The soil VOC concentrations detected at OU4 to date do not exceed the levels associated with acceptable exposures, risks and/or hazards. Further, the results of personal breathing zone and real time air sampling performed during water and sludge sampling, and breathing zone air sampling during pondcrete puck reprocessing operations are provided in Appendix B. These data demonstrate that the airborne VOC exposure levels measured for the OU4 workers are very low and are below applicable OSHA and ACGIH standards for the protection of workers.

The greatest exposure to airborne VOCs from OU4 soils and sediments would be experienced by receptors who are in the closest proximity to the emissions source. As VOCs are dispersed into the atmosphere, the air concentrations will be diluted and the VOCs will also be subject to degradation (through photolysis and reactions with free radical species). Thus, the farther the distance between the emissions source and the receptor, the lower the potential exposure concentration for the receptor.

With respect to OU4, then, the onsite workers would potentially receive the greatest exposure to VOCs in air compared to more distally located receptor populations. The data in Appendices B and C indicate that the onsite worker would receive very minimal exposure to VOCs through potential inhalation of VOCs released from OU4 soil and pond sediment. Therefore, inhalation of VOCs will only be assessed quantitatively in the risk assessment if the results of the OU4 Phase I sampling programs show that the VOC concentrations exceed the concentrations derived in Appendix C.

4.5 CONCEPTUAL SITE MODEL

Information concerning waste sources, waste constituent release and transport mechanisms, and locations of potentially exposed receptors is used in this section to develop a conceptual understanding of the site in terms of potential human exposure pathways. Figure 4-1 shows a CSM of potential human exposure pathways for OU4. As noted in Section 1.2, the nature and extent of contamination in surface water and groundwater will not be investigated until the Phase II RFI/RI. Therefore, this technical memorandum addresses only direct and upward exposure pathways. Potential downward pathways are shown in the CSM in order to put the current scope of analysis in context with the overall remedial action analysis.

The CSM is a schematic representation of the chemical source areas, chemical release mechanisms, environmental transport media, potential human intake routes, and potential human receptors. The purpose of the CSM is to provide a framework for problem definition, identify exposure pathways that may result in human health risks, indicate data gaps, and aid in identifying appropriate remediation measures. Chemical release mechanisms, environmental transport media, and potential human intake routes to the contaminated site source materials and soil were identified for each potentially exposed receptor and are discussed below in Section 4.5.1.

As shown in the CSM, professional judgement was used to identify potentially complete and incomplete exposure pathways. All potentially complete exposure pathways, regardless of the relative significance or insignificance of exposure pathways, are designated on the CSM as complete exposure pathways. Quantitatively addressing potentially complete exposure pathways will provide for risk estimates that are conservative and do not underestimate actual risks.

4.5.1 Sitewide Incomplete or Negligible Exposure Pathways

The following OU4 exposure pathway has been determined to be incomplete for all receptors. These pathways will not be quantitatively addressed in the risk assessment.

- Inhalation of volatiles in outdoor and indoor air by all current and future receptors;
- Oral intake of chemicals in vegetables and plants by site workers; and
- Direct contact exposures (oral, dermal, and groundshine) for current off-site residents.

No other sitewide incomplete exposure pathways is believed to exist for the site. Specific exposure pathways that will be evaluated for each exposure scenario are described below by receptor.

4.5.2 Potentially Complete Exposure Pathways

4.5.2.1 Current Onsite Worker

For the purposes of this evaluation, it is assumed that the population of current onsite workers consists of those individuals involved with operations, maintenance, and surveillance of the Solar Ponds area. As indicated on the CSM, it has been determined that these current onsite workers could potentially be exposed to site-related compounds via inhalation of wind-suspended particulate matter from the pond soil and sediment areas, as well as via direct contact with (i.e., ingestion of and dermal contact with) site soils. Therefore, exposures incurred via inhalation or direct contact are included in this evaluation.

Owing to the close proximity of the pond operations/maintenance workers with the Solar Pond area, it is anticipated that this population would be the most likely to incur exposure to particulate emissions from the pond soils. However, because these workers are not continuously working on the ponds site, and because exposures would occur in an outdoor environment where emissions of particulates would become diluted, it is expected that these exposures would be relatively insignificant.

Because of the nature of the work on the ponds, these onsite workers would be expected to incur exposures to airborne particulates. However, the limited daily duration of exposure of workers in the pond area, the low likelihood that they will spend significant amounts of time downwind from the pond area, and the fact that current onsite workers are operating under an occupational health and safety plan suggest that exposure to airborne particulates would also be relatively insignificant. To ensure that final estimates of exposure (and the associated risk) are health-conservative, potential exposure to airborne particulates will be included in the evaluation of exposures potentially incurred by the current onsite workers.

Because the current onsite workers are active in the Solar Ponds Area, it is assumed that these individuals will come into direct contact with the site soils and could therefore, incur incidental ingestion exposures as well as direct dermal contact with soils and groundshine. Dermal contact would be limited to exposure to organic compounds in soil. As with inhalation exposures, the magnitude of these exposures should be mitigated since the ponds workers are specifically trained and working under an occupational health and safety plan. Therefore, as indicated on the CSM, these exposures are assumed to be potentially complete and are included in the assessment in order to be comprehensive and health-conservative.

External irradiation from decay of radioactive materials in contaminated surface soils (groundshine) is also a potentially complete but insignificant exposure pathway. Radioactive materials have been detected in the soil above sitewide background levels. Therefore, external radiation from direct contact with the soil will be evaluated as a potentially complete exposure pathway for the current onsite worker.

Several exposure pathways are considered to be incomplete for the current onsite worker. First, it is assumed that there will be no exposures to indoor air because there are currently no structures on the site. As described in Section 4.4, inhalation exposure to VOCs will not be evaluated because the potential exposures have been shown to be negligible based on the air monitoring results provided in Appendix B and the air modeling analysis presented in Appendix C. Second, it is assumed that secondary exposure to soils following wind deposition of particulates is negligible relative to direct exposures to site soils. Finally, all exposures incurred via ingestion of plants (particulate deposition and plant uptake) are incomplete exposure pathways because no edible crops are grown on the site for workers to ingest.

In summary, potentially complete human exposure pathways for the current onsite workers are:

- Inhalation of airborne particulates;
- Incidental soil ingestion from direct contact;
- Direct dermal contact with site soils; and
- Groundshine (direct contact).

4.5.2.2 Current Offsite Resident

As the CSM for the current offsite resident indicates, airborne dispersal following volatilization or suspension of particulates is the primary transport mechanism from contaminated site soils to the current offsite resident. Therefore, exposures associated with exposure of the current offsite residents to site-related compounds in the air or particulates deposited onto soils and vegetation are included in the evaluation.

Direct ingestion and dermal contact with site soils and onsite external irradiation from radioactive decay of radionuclides on site soils are also primary release mechanisms but are incomplete exposure pathways for offsite receptors because site access is restricted. Therefore, current offsite residents could not come into direct contact or even close proximity to contaminated soils on site. Similarly, exposure to site contaminants from consumption of vegetables that have taken up compounds directly from site soils is an incomplete pathway because offsite residents would not have access to vegetation grown onsite.

Chemicals bound to soils transported via wind as particulates represent potential inhalation, oral, and dermal exposure pathways. It is also expected that these exposures will be relatively insignificant because of the effect of dilution on particulate matter air concentrations. Current offsite residents may be directly exposed to airborne particulates via inhalation; consequently, this is a potentially complete pathway. Homegrown garden vegetables subject to deposition of airborne particulates from the sites also represent a potentially complete ingestion pathway. Similarly, contaminated soil (from deposition of airborne particulates) provides potentially complete oral and dermal exposure pathways for this receptor.

Plant uptake of contaminants deposited as windblown particulates on soil may potentially occur. However, this uptake is considered to provide a potentially insignificant contribution to overall exposure for the following reasons:

- As mentioned in Section 4.4, metals and many organic compounds bind tightly to soil, thus greatly reducing their bioavailability to plants (EPA 1991a); and
- Chemical concentrations from particulates deposited on residential soil will be significantly diluted by tilling. Tilling will mix the thin layer of surface soils that are impacted by site-related contaminants in with several inches of soils that are not impacted.

For these reasons, chemical concentrations in garden vegetables that result from surface deposition of contaminated particulates are expected to be greater than those from uptake by vegetables from the soil. Therefore, current residential intake of vegetables will only be evaluated for surface disposition of particulates on plants.

In summary, potentially complete human exposure pathways for the current offsite resident include:

- Inhalation of airborne particulates;
- Soil ingestion following airborne deposition of particulates on residential soil;
- Dermal contact with soil, following airborne deposition of particulates; and
- Ingestion of vegetables following surface deposition of particulates.

4.5.2.3 Hypothetical Future Onsite Worker

In order to characterize exposures that could potentially occur should the site be developed into office buildings, this assessment includes an evaluation of a hypothetical future onsite office worker who is exposed indoors during the work day and outdoors during a lunch break.

As the CSM for the future onsite worker indicates, wind suspension and direct contact are the primary chemical release mechanisms from the site to this exposed population.

Chemicals bound to soil particles suspended and transported by the wind represent negligible oral and dermal exposure pathways; however, future onsite workers may be exposed to airborne particulate matter via inhalation. Inhalation is considered to be a potentially complete and significant pathway due to proximity to the source. Direct contact with contaminated soil represents potentially complete oral and dermal exposure pathways. Dermal contact would be limited to organic compounds in soil. Because of the dilution effect during wind transport of contaminated soil, the oral and dermal pathways from wind suspension are negligible compared to direct oral and dermal exposures to the soil by onsite workers. It is assumed that site workers would not consume vegetation grown onsite. Therefore, wind deposition and plant uptake of site-related compounds are considered incomplete for the hypothetical future onsite workers.

External irradiation from decay of radioactive materials in contaminated surface soils (groundshine) is also a potentially complete exposure pathway. Radioactive materials have been detected above site-wide background levels. Therefore, external radiation from direct contact with the soil will be analyzed as a potentially complete human exposure pathway for the hypothetical future onsite worker.

Exposure to radioactive materials via ingestion, oral, or dermal uptake routes is accounted for in the other potentially complete exposure pathways described for this receptor.

In summary, potentially complete human exposure pathways for the future onsite worker are:

- Inhalation of airborne particulates;
- Incidental soil ingestion;
- Direct dermal contact with soil; and
- Groundshine (direct contact).

4.5.2.4 Hypothetical Future Onsite Ecological Researcher

As the CSM indicates, it has been determined that wind suspension and direct contact are the primary release mechanisms that are part of complete exposure pathways from site soils to a future onsite ecological researcher. External radiation exposure from contaminated soils is also a potentially complete pathway.

Chemicals that volatilize from the site may be released to indoor air and outdoor air. Inhalation of VOCs in outdoor air is considered to be a relatively insignificant pathway. Inhalation of indoor air is an incomplete exposure pathway for an ecological researcher because the researchers will spend their time outdoors while on site.

These primary release mechanisms have associated exposure routes that are potentially complete for the future ecological researcher. Chemicals bound to soils that are released via wind as particulate matter represent potential inhalation, oral, and dermal exposure pathway following deposition. Of these, exposures to airborne particulate matter via inhalation is potentially significant because the receptor is located so near the source area. The impact of incidental ingestion of contaminated soil and dermal absorption of chemicals in soil following wind deposition are considered to be negligible in comparison to the potential exposures incurred via direct ingestion and dermal exposure to site soils. For direct contact with site soils, incidental ingestion is expected to be potentially significant. Relative to these ingestion exposures, dermal exposure is expected to be insignificant.

It is assumed that an ecological researcher working at RFP would not consume vegetation grown on the site. Therefore, wind deposition of particulates onto plants and subsequent uptake of these contaminants are considered to be incomplete exposure pathways for the researcher scenario.

External irradiation from decay of radioactive materials in contaminated site surface soils (groundshine) is also a potentially complete exposure pathway. Radioactive materials have been detected in the Solar Pond Area soil above sitewide background levels. Therefore, external radiation from direct contact with the soil will be analyzed as a potentially complete human exposure pathway.

Exposure to radioactive chemicals via ingestion, oral, or dermal uptake routes other than external irradiation is accounted for in the other potentially complete exposure pathways described for this receptor.

In summary, potentially complete exposure pathways for chemicals released from contaminated site soils for the future ecological researcher are:

- Inhalation of airborne particulates;
- Incidental soil ingestion;
- Direct dermal contact with soil; and
- Groundshine (direct contact).

4.5.2.5 Hypothetical Future Onsite Construction Worker

As the CSM indicates, it has been determined that wind suspension and direct contact are the primary release mechanisms that are part of complete exposure pathways from site soils to a future onsite construction worker. External radiation exposure from contaminated soils is also a potentially complete pathway.

These primary release mechanisms have associated exposure routes that are potentially complete for the future construction worker. Chemicals bound to soils that are released via wind as particulate matter represent potential inhalation, oral, and dermal exposure pathways following deposition. Of these, exposures to airborne particulate matter via inhalation is potentially significant because the receptor is located so near the source area. The impact of incidental ingestion of contaminated soil and dermal absorption of chemicals in soil following wind deposition are considered to be negligible in comparison to the potential exposures incurred via direct ingestion and dermal exposure to site soils. For direct contact with site soils, incidental ingestion is expected to be potentially significant. Relative to these ingestion exposures, dermal exposure is expected to be insignificant.

It is assumed that a construction worker employed at RFP would not consume vegetation grown on the site. Therefore, wind deposition of particulates onto plants and subsequent uptake of these contaminants are considered to be incomplete exposure pathways for the construction worker scenario.

External irradiation from decay of radioactive materials in contaminated site surface soils (groundshine) is also a potentially complete exposure pathway. Radioactive materials have been detected in the Solar Pond Area soil above sitewide background levels. Therefore, external radiation from direct contact with the soil will be analyzed as a potentially complete but relatively insignificant human exposure pathway.

Exposure to radioactive chemicals via ingestion, oral, or dermal uptake routes other than external irradiation is accounted for in the other potentially complete exposure pathways described for this receptor.

In summary, potentially complete exposure pathways for chemicals released from contaminated site soils for the future construction worker are:

- Inhalation of airborne particulates;
- Incidental soil ingestion;
- Direct dermal contact with soil; and
- Groundshine (direct contact);

4.5.2.6 Hypothetical Future Onsite Resident

As the CSM indicates, wind suspension, uptake of compounds into plants, and direct contact are all chemical release mechanisms that are part of complete exposure pathways from site soils to a hypothetical future onsite resident.

Chemicals bound to soil particles suspended and transported by wind are negligible oral and dermal exposure pathways, but inhalation of these particulates presents a potentially significant route of exposure to site-related compounds. Because this receptor is located directly on the site, the oral and dermal exposures contributed from wind deposition of particulates will be negligible compared to the oral and dermal exposures that are anticipated to result from direct contact with site soils. Hence, incidental soil ingestion and dermal exposure from wind-deposited soils will not be included in this assessment. Airborne deposition of soil-bound contaminants onto the surface of vegetables grown on the site could, however, be potentially significant and is therefore included in the evaluation of potential future onsite residential exposures. For direct contact with site soils, the exposures resulting from incidental ingestion are expected to be potentially significant. Relative to these ingestion exposures, dermal exposure will be insignificant because of the effectiveness of skin as a barrier to contaminant absorption and the impact of the matrix effect on the release of contaminants.

Hypothetical future onsite residents could maintain home gardens. Vegetables grown in these gardens could accumulate site-related contaminants as a result of both uptake from site soils and deposition onto exposed surfaces. Because the hypothetical future resident is assumed to live directly on the site, vegetables grown by these residents could be in direct contact with impacted soils. This assessment assumes that site soils are not tilled prior to planting, so no dilution of site contaminants would occur.

Deposition of particulates onto the surface of vegetables may contribute to the concentration of chemicals in a plant (Whicker 1990). Particulate deposition and subsequent absorption or adherence to edible plant tissues in a highly complex and dynamic process. For example, deposition onto exposed portions of food crops must be balanced against removal by weathering and senescence (McKone and Daniels 1991). A multitude of assumptions must be made to estimate atmospheric deposition of particulate bound chemicals and radionuclides and subsequent concentration in food plants. The literature (i.e., including *Transuranium Elements*, EPA 1990b) will be consulted to identify appropriate dust loading and washoff factors for evaluating the particulate deposition pathway. DOE will submit the proposed factors for EPA approval prior to proceeding with the development of the particulate deposition evaluation.

Although root uptake is comparatively unimportant, at least for long-lived contaminants in soils, evaluation of potential human exposures to site-related chemicals from consumption of plants will include possible root uptake to ensure that final estimates of exposure are conservative. Chemicals and radionuclides in a soil matrix may be taken up through the roots and translocated into edible portions of the plant. Uptake studies on plutonium and other transuranics have provided estimates of the relationship between plant uptake and the concentration in soil. Such information can be used to estimate concentrations of radionuclides in homegrown vegetables. Chemical specific uptake values for non radionuclides will be used based on availability of uptake values in the literature. DOE will confer with EPA with regard to identifying appropriate uptake factors for use in evaluating the root uptake pathway.

It has been demonstrated that resuspension and deposition of particulates onto the surface of vegetables can dominate contaminant concentrations in plants (Whicker 1990). Although root uptake is comparatively unimportant, at least for long-lived contaminants in soils, evaluation of potential human exposures to site-related chemicals from consumption of plants will include possible root uptake to ensure that final estimates of exposure are conservative.

External irradiation from decay of radioactive materials in contaminated site surface soils (groundshine) is also a potentially complete exposure pathway. Radioactive materials have been detected in the OU4 soils above sitewide background levels. Therefore, external radiation from direct contact with the soil will be analyzed as a potentially complete human exposure pathway.

Exposure to radioactive chemicals via ingestion, oral, or dermal uptake routes other than external irradiation is accounted for in the other potentially complete exposure pathways described for this receptor.

In summary, potentially complete human exposure pathways for chemicals released from contaminated site soils for the hypothetical future onsite resident are:

- Inhalation of airborne particulates;
- Ingestion of homegrown vegetables (surface deposition of particulates and root uptake of site-related chemicals);
- Incidental soil ingestion ;
- Direct dermal contact with soil;
- Groundshine (direct contact).

A summary of potentially complete exposure pathways that will be quantitatively evaluated in the baseline human health risk assessment is provided in Table 4-1.

5.0 ESTIMATING CHEMICAL INTAKES

This section presents reasonable maximum intake parameters for each of the receptors and exposure pathways identified in previous sections. Specific chemical intakes are not presented in this memorandum since they are dependent on pending site characterization to provide exposure point concentrations.

Using the exposure point concentrations of chemicals in soils and air, it is possible to estimate the potential human intake of those chemicals via each exposure pathway. Intakes are expressed in terms of chemical (mg)/body weight (kg)/day. Intakes are calculated following guidance in *Risk Assessment Guidance for Superfund Human Health Evaluation Manual, Supplemental Guidance: "Standard Default Exposure Factors"* (EPA, 1989a) and *"Calculating the Concentration Term"* (EPA, 1992d), and *Exposure Factors Handbook* (EPA 1989b), other EPA guidance documents as appropriate, and professional judgment regarding likely site-specific exposure conditions. Intakes are estimated using reasonable estimates of body weight, inhalation volume, ingestion rates, soil or food matrix effects, and frequency and duration of exposure.

Intakes are estimated for reasonable maximum exposure (RME) conditions. The RME is estimated by selecting values for exposure variables so that the combination of all variables results in the maximum exposure that can reasonably be expected to occur at the site.

The general equation for calculating intake in terms of mg/kg/day is:

$$\text{Intake} = \frac{\text{chemical conc.} * \text{contact rate} * \text{exposure freq.} * \text{exposure duration}}{\text{body weight} * \text{averaging time}}$$

The variable "averaging time" is expressed in days to calculate daily intake. For noncarcinogenic chemicals, intakes are calculated by averaging over the period of exposure to yield an average daily intake. For carcinogens, intakes are calculated by averaging the total cumulative dose over a lifetime, yielding "lifetime average daily intake." Different averaging times are used for carcinogens and noncarcinogens because it is thought that their effects occur by different mechanisms of action. The approach for carcinogens is based on the current scientific opinion that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime. Therefore, for whatever exposure duration, the intake of a carcinogen is averaged over a 70-year lifetime (EPA 1989a). Intake of noncarcinogens is averaged over the period of exposure since the average concentration of a noncarcinogen is compared with the threshold dose for an effect.

Omitting chemical concentrations from the intake equation yields an "intake factor" that is constant for each exposure pathway and receptor. The intake factor can then be multiplied by the concentration of each chemical to obtain the pathway-specific intake of that chemical. Intake factors are calculated separately for each potentially exposed receptor and exposure pathway that was identified in Section 4.5. Because contact rates (except for soil ingestion) are approximately proportional to body weight, child residential intakes are not estimated separately for any exposure pathway except soil ingestion, for which children are assumed to have higher daily intake rates. The assumptions used in deriving intake factors are discussed below.

5.1 INTAKE FACTOR ASSUMPTIONS

Several exposure parameters, such as exposure duration, body weight, and averaging times, have general application in all intake estimations, regardless of pathway. These general assumptions, as well as pathway-specific assumptions, are detailed in the section below. The term "occupational exposures" includes exposures to both the future onsite worker and the hypothetical future ecological researcher. In general, conservative parameter value assumptions were made in order that the resulting exposure estimates would be over-, rather than underestimated.

5.1.1 General Exposure Assumptions

- For all exposure scenarios, the RME exposure frequency has been estimated to be 5 days/week for 50 weeks/year for the current onsite worker, 7 days/ week for 50 weeks for the current and future offsite resident (EPA 1991b), 5 days/week for 50 weeks for the hypothetical future onsite worker and future onsite construction worker (EPA 1991b), and 5 days/week for a 16 week field season for the ecological researcher. Where appropriate, exposure frequencies are then adjusted to account for snowfall in the area, assuming that accumulation of snow on the ground will obscure exposures. Based on information from the Assistant State Climatologist for Colorado (Doesken 1992), the 30-year average precipitation record indicates that there is at least 1 inch of snow cover on the ground for 60 days each year;

- Residential RME exposure duration is assumed to be 30 years (EPA 1991b);

- The RME exposure duration for the current ponds worker is assumed to be 5 years, based on the assumption that the solar ponds will be closed within this period;

- Occupational RME exposure durations for hypothetical future onsite workers are assumed to be 25 years. This reasonable maximum duration is the 95th percentile duration of work at the same location (EPA 1991b);

- Averaging time for exposure to non-carcinogenic compounds is the product of the exposure duration and the number of days in a year (365);

- Averaging time for carcinogenic effects is 70 years (25,550 days) in the reasonable maximum case; and

- The average adult body weight is assumed to be 70 kg (EPA 1989b).

5.1.2 Inhalation Assumptions

Uptake of chemicals through inhalation is a function of the volume of air inhaled per day, the exposure frequency and duration, and pulmonary deposition (for particulate inhalation). Intake factors for exposure via particulate or VOC inhalation were estimated for appropriate receptors. The following assumptions will be used to estimate exposure to chemicals of concern through this route.

- The RME respiratory volume of air for all residential receptors is assumed to be 0.83 m^3/hr (20 m^3/day). This is a suggested average value for continuous (i.e., 24-hour) exposures (EPA 1991b);

- Current and future onsite occupational receptors are assumed to breathe onsite air 4 or 8 hours/day, respectively in the RME case;

- Current and future residential receptors are assumed to be exposed for 24 hours/day in the RME case. This exposure frequency incorporates the health-conservative assumption that residential receptors are at home all day; and

- Twenty-five percent of inhaled particles are deposited in the lung; it is assumed that all chemicals in that fraction are absorbed (MRI 1985).

5.1.3 Soil Ingestion Assumptions

Uptake of chemicals via incidental ingestion of soil and dust is a function of the ingestion rate, the fraction of ingested (FI) soil or dust that is contaminated, the frequency and duration of exposure, and the bioavailability of the chemical adhered to the particulates ingested.

The calculation of an RME 30-year residential exposure to soil will be divided into two parts. First, a six-year exposure duration is evaluated for young children, thus accounting for the period of highest soil ingestion and lowest bodyweight. Second, a 24-year exposure duration is assessed for older children and adults using a lower soil ingestion rate. By time-averaging the child residential soil ingestion exposures with the exposures calculated for the adult, a child residential exposure from soil ingestion is taken into account.

Intake factors for exposure via soil ingestion were calculated for current pond workers, an adult resident, a child resident, a future hypothetical onsite ecological researcher, a hypothetical future onsite worker, a hypothetical future onsite construction worker and a hypothetical future onsite resident. The following assumptions will be used in estimating intake through this route.

- Occupational receptors are assumed to ingest 50 mg/day of soil in the RME case (EPA 1991b);

- The calculation of a 30-year residential exposure to soil is time-averaged by assessing a six-year childhood exposure duration followed by a 24-year adult exposure duration. The six-year exposure duration is evaluated for young children, and this accounts for the period of highest soil ingestion (200 mg/day) and lowest body weight (15 kg) (EPA 1991b). The 24-year exposure duration is assessed for older children and adults and accounts for the period of lower soil ingestion (100 mg/day) and an adult body weight (70 kg) (EPA 1991b);

- EPA guidelines allow for the use of professional judgement in the determination of the parameter value for the fraction ingested variable. For OU4, the FI from the contaminated source is assumed to be 0.5 for current ponds workers, 0.125 for the future onsite worker, 0.006 for the hypothetical future onsite ecological researcher and hypothetical future onsite construction worker, and 0.5 for the current and future residential receptor. The FI of 0.5 for current onsite workers assumes that 4 hours of each day are spent in the Solar Ponds Area. The FI for the future onsite worker is based on 1 hour of exposure to contaminated soil per 8-hour workday. This assumes that the onsite worker spends his/her entire lunch hour outside. The future onsite ecological researcher and construction worker is assumed to spend time at OU4 in relative proportion of the area of OU4 to the area of the total buffer zone during a career of research/construction work at RFP. Residential receptors are assumed to be exposed to contaminated soils for 50 percent of the time that they are present at their homes; and

- The matrix effect of soil on bioavailability of ingested contaminants can be significant and will be evaluated for all soil ingestion exposures on a chemical-specific basis. The matrix effect describes the reduced availability of site-related chemicals due to adsorption of chemicals to soil compared to the same chemical dose administered in solution. Therefore, the soil matrix has the effect of reducing chemical intake. The chemical-specific matrix effects cannot be determined until the chemicals of concern are identified for OU4.

5.1.4 Homegrown Produce Ingestion Assumptions

It is assumed that contamination of homegrown produce may occur by root uptake of chemicals into the plant. Human exposure to chemicals via ingestion of homegrown vegetables is a function of the ingestion rate, the fraction of contaminated homegrown produce ingested, the frequency and duration of exposure, and the amount and bioavailability of the chemical adhered to, or taken up into, the produce ingested. An intake factor for exposure via vegetable ingestion was calculated for current and hypothetical future residential receptors. Current or future onsite workers, construction workers and ecological researchers are not expected to ingest produce from the site. The following assumptions will be used in estimating intake through this route.

- Current offsite and hypothetical future onsite residential receptors are assumed to ingest an annual average of 26,667 mg/day of site-impacted vegetables in the RME case. This RME figure is based on the "typical" consumption value of vegetables (200,000 mg/day), assuming a "reasonable worst case" proportion of 40 percent being homegrown (EPA 1991b) and a 4-month harvesting season;

- Homegrown vegetables are assumed to be potentially contaminated by surface deposition of airborne particulates from OU4 soils at both offsite and onsite locations. Modeled soil loading rates will be applied to reasonable maximum estimates of vegetable surface areas, weights, and human consumption rates to estimate chemical intake from this potential exposure pathway. For hypothetical future onsite residential exposure, it is also assumed that plants may contain site-related chemicals following root uptake. Anticipated chemical concentrations in plants will be calculated using values available in the literature; and

- The matrix effect of produce on bioavailability of ingested contaminants will be evaluated on a chemical-specific basis, and is assumed to be the same as the values used for soil ingestion where contaminants are present as a result of surface deposition.

Reductions in chemical concentrations due to washing, cooking, or peeling of produce are not accounted for although they may have a significant effect on concentrations. Thus, these calculations yield a health-conservative estimate of exposure.

5.1.5 Dermal Contact with Organic Compounds Soil

Uptake of organic chemicals of concern through dermal contact with surface soil is a function of body surface area, absorbed fraction, an adherence factor that describes how much soil adheres to skin, the fraction of soil contacted that is from a contaminated source, and exposure frequency and duration. As described in the above discussion of Uptake Mechanisms (Section 4.4), dermal uptake of metals is expected to be negligible and is not addressed in this assessment. Dermal contact with surface soil will only be evaluated if sampling demonstrates the presence of organic compounds. The following assumptions will be used to estimate exposure to chemicals of concern through dermal contact with organic compounds in soil for all receptors.

- The RME exposed body surface area for all receptors is assumed to be 2,190 cm^2. The reasonable maximum surface area is assumed to be equivalent to face, forearms, and hands (or 15 percent of total body surface area) (EPA 1989b);

- The absorbed fraction is the estimated fraction of organic compounds (if available) adhered to soil particles that partitions to and is absorbed through skin. This fraction is chemical-specific. Percent absorbed depends upon soil loading, organic carbon content of soil, contaminant concentration, duration of exposure, animal species used in the experiment, and whether the experiment is conducted in vitro or in vivo. The absorbed fraction will be determined on a chemical-specific basis using data available in the scientific literature;

- The soil adherence factor used is 0.6 mg/cm^2 in the RME case. This value represents the midpoint in the range of currently recommended values for soil adherence (EPA 1992b); and

- The fraction contacted (FC) from the contaminated medium is assumed to be 0.5, 0.125, 0.006, and 0.5 in the RME case for the current onsite worker, future onsite worker, the future onsite ecological researcher and future onsite construction worker, and the current and future residential receptor, respectively. The FC for the current onsite worker is based on an assumed 4 hours of exposure to site soils per 8-hour work day. The FC for the future onsite worker is based on 1 hour of exposure to contaminated soil per 8-hour workday. The future onsite ecological researcher and future onsite construction worker are assumed to conduct field research/construction activities at OU4 in relative proportion of the area of OU4 to the area of the total buffer zone at RFP. Residential receptors are assumed to be exposed to contaminated soil for 50 percent of the time that they are at their residence. This fraction assumes that 16 hours per day are spent at home and 8 hours per day are spent away from home at work or school. Of the 16 hours spent at home, it is assumed that 8 hours are spent indoors and the remaining 8 hours are spent outdoors in activities that may potentially involve dermal contact with contaminated soil.

5.1.6 Internal Exposure to Radionuclides

Intake of radionuclides by ingestion, inhalation, or absorption (which leads to incorporating the radionuclides into the tissues and organs of the body) will result in a radiation dose to those organs as well as to surrounding tissues. This intake is a function of the radionuclide concentration and the frequency and duration of exposure to the radioactive material. Calculation of intake rates for radionuclides from the environment into the body can be made in the same manner as other nonradioactive chemicals except neither averaging time nor body weight are used as parameters. The resulting calculation is an estimate of the radionuclide intake, expressed in units of radioactivity (e.g., Bq or Ci) (EPA 1989a).

Internal and external exposure will be combined so that pathways can be summed to estimate total exposure and risk.

The radiation dose from the intake of radioactive material is a function of the type of radiation emitted by the radionuclide. The dose equivalent was developed to normalize the unequal biological effects from the different types of radiation. Because radiation doses from systemically incorporated radionuclides may continue long after the intake of the nuclide has ceased, doses to specific tissues and organs from internal radionuclides are typically reported in terms of the committed dose equivalent. The committed dose equivalent to specific organs as a result of intake of the radioactive material is estimated by multiplying the intake of each radionuclide by the appropriate dose conversion factor (DCF). The committed dose equivalents for each radionuclide are then summed to obtain a total committed dose equivalent. Internal exposures to radionuclides will be calculated using this approach to compare exposures with applicable standards given in terms of committed dose equivalents.

5.1.7 External Irradiation

To estimate risks from exposure to radiation from sources outside the body, average radionuclide concentrations in the ponds material (Bq/gm or Pci/gm), whether directly measured or estimated by modeling, are multiplied by the appropriate slope factor for radionuclide carcinogenicity from the *Health Effects Assessment Summary Tables* (EPA 1992c) and the exposure duration (years). The slope factor for radionuclide carcinogenicity is based on an exposure time of 24 hours per day and an exposure frequency of 365 days per year.

Risk from external irradiation may be estimated by multiplying the slope factor times the radionuclide concentration and an exposure factor. The exposure factor is analogous to an intake factor and is calculated as:

$$\text{Exposure factor} = \frac{\text{Exposure time x exposure frequency x exposure duration}}{\text{Baseline exposure time x baseline exposure frequency}}$$

Dividing of RME exposure times and exposure frequencies by the baseline values of 24 hours per day and 365 days per year accommodates exposure scenarios that are not continuous.

5.2 INTAKE FACTOR CALCULATIONS

The assumptions and values described above will be used to calculate intake or exposure factors for each exposure pathway and receptor. Parameters to be used for calculations of intake and exposure factors are shown in Tables 5-1 through 5-21. Exposure point concentrations will be used with these parameters to obtain pathway-specific intakes or exposures.

Effective dose equivalents will also be calculated for potential onsite OU4 workers. The estimates of dose equivalent will be used for comparison with radiation protection standards and criteria which have been developed for the protection of occupational receptors. The dose equivalent will be estimated using appropriate IRCP and EPA guidelines (IRCP, 1979; EPA, 1988).

5.2.1 Exposure Point Concentrations

The sampling results for the OU4 soils will be divided into two exposure source areas, namely: 1) the Solar Ponds Area, comprised of the surface impoundments and adjacent areas; and 2) the Hillside Area, comprised of the area below the Solar Ponds Area. The rationale for categorizing the source areas is based on the differences between the two source areas with respect to the soils composition and historical areal use. The Solar Ponds Area has been used for pond operation and maintenance, storage, etc, and represents an industrial area. The Hillside area has not been an active area of operations and is characterized by a steep vegetated slope. The Solar Ponds area is frequented by current site workers on a daily basis. However, current site workers do not perform daily operations or maintenance work in the Hillside Area with any regular frequency.

Exposure point concentrations will be determined for the two source areas according to the EPA "Supplemental Guidance to RAGS: Calculating the Concentration Term" (EPA, 1992d; OSWER Publication No. 9285.7-081) and the Human Health Evaluation Manual Requirements (EPA, 1989a). The exposure concentration for the RME evaluation will consist of the 95 percent upper confidence level (UCL) or maximum concentration detected (whichever is lower in magnitude) in the Solar Ponds Area and Hillside Area. The methodology outlines in EPA's supplemental OSWER No. 9285.7-081 guidance for determining exposure point concentrations is admittedly problematic in that the results for positively skewed data sets may provide overestimates of the 95 percent UCL. Thus, in such cases the maximum concentration detected may be utilized.

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Table 3-1 Current and Projected Population in the OU4 Exposure Assessment Area

Year 1989/2010						
Sector	D	E	F	G	H	I
1	0/0	0/0	0/0	0/0	0/0	0/0
2	0/0	0/0	0/0	0/0	0/0	0/0
3	0/0	0/0	0/0	17/17	0/0	7/7
4	0/14	283/644	46/142	50/50	215/1007	3/3
5	25/25	3671/5009	477/601	578/1879	2355/10186	469/2124

Source: DOE 1990. *1989 Populaton, Economic, and Land Use Data for Rocky Flats Plant.*

Table 3-2 Rocky Flats Plant OU4 Current Surrounding Land Use In Jefferson County

Parcel #	Current Use/Project Name	Zoning[1]	Land Use Type
22009			
44001	Vacant	A-2	Vacant
44002			
44003	Vacant	I-1	Industrial
44004	Vacant	A-2	Vacant
44005			
44006	Vacant	I-3	Industrial
44007	Vacant	A-2	Vacant
45001			
45002	Walnut Creek Unit 1	P-D	Single Family - Detached
45002	Walnut Creek Unit 1	P-D	Retail
45003	Vacant	A-2	Vacant
45004	Single Family - Detached	A-2	Single Family - Detached
45005	Single Family - Detached	A-2	Vacant
45006	Water	A-2	Water
45007	Single Family - Detached	A-2	Single Family - Detached
45007	Single Family-Detached	A-2	Farm/Ranching
46005	Vacant	A-2	Single Family - Detached
46006	Triple C Quarter Horses	A-2	Retail
46007	Horse Barn-Boarding & Breeding	A-2	Retail
46008	Single Family - Detached	A-1	Single Family - Detached
46009	Single Family - Detached	SR-2	Single Family - Detached
46011	Mountain View Tech Center	P-D	Industrial
46012	Jefcope	P-D	Industrial
46017	Water	A-2	Water
46019	Single Family - Detached	A-2	Single Family - Detached
47036	Vacant	SR-2	Single Family - Detached
47040			
71001	Rocky Flats	A-2	Industrial
72001	Vacant	I-2	Industrial
72002	Vacant	A-2	Vacant
72003	Single Family - Detached	A-2	Single Family - Detached

Table 3-2 Rocky Flats Plant OU4 Current Surrounding Land Use In Jefferson County (cont.)

Parcel #	Current Use/Project Name	Zoning[1]	Land Use Type
22009			
72004	Vacant	I-2	Vacant
72004	Vacant	I-2	Industrial
72005	Tosco Flg 1	I-2	Industrial
72006	Rocky Flats Ind Park Flg 2	I-2	Industrial
72007	Rocky Flats Ind District Flg 1	I-2	Industrial
72008	Water Tank Ralston Val Stn 2	I-2	Utilities
72009	Vacant - Rocky Flats	A-2	Industrial
72010	Vacant	I-2	Industrial
72011	Northwest Industrial	I-2	Industrial
72012	Vacant	A-2	Vacant
72013			
73001	Vacant	A-2	Vacant
73005	Wheat Ridge Gardens	A-2	Vacant
73019	Vacant	A-1	Vacant
73020	Single Family - Detached	SR-2	Single Family - Detached
73021	Vacant	RC	Office/Retail
73022	Westminster Gardens	A-2	Single Family - Detached
99001	Great Western Aggregate Quarry	I-1	Industrial
99005	Sawmill Operation	I-2	Industrial
99006	Great Western Aggregates	I-2	Industrial
99007	Vacant	I-2	Industrial
99008	Colorado Brick Comp Clay Mine	M-C	Mining
99009	Vacant	I-2	Industrial
100001	Rock Creek Ind Park Vacant	P-D	Industrial
100002	Vacant	I-1	Industrial
100003	Rocky Flats - Vacant	I-1	Industrial
100004	Rocky Flats - Clay Extraction	M-C	Industrial
100005	Rocky Flats - Vacant	I-2	Industrial
100006	Electric Substation	M-C	Utilities
100006	Gravel Mine	M-C	Industrial
101001	Vacant	A-2	Vacant
101002	Vacant	M-C	Industrial

Table 3-2 Rocky Flats Plant OU4 Current Surrounding Land Use In Jefferson County (cont.)

Parcel #	Current Use/Project Name	Zoning[1]	Land Use Type
22009			
101003	Vacant	I-2	Industrial
101004	Mine and Water	I-2	Industrial
101005	Northwest Industrial	I-2	Industrial
101006	Vacant	M-C	Industrial
101007	Sanitary Ponds and Gravel	P-DA	Industrial
101008	Rocky Flats Lake	M-C	Water

1 Zoning Abbreviations are as follows:

A-1	Agricultural 1
A-2	Agricultural 2
I-1	Industrial 1
I-2	Industrial 2
I-3	Industrial 3
P-D	Planned Development
SR-2	Suburban Residential 2
RC	Restricted Commercial
P-DA	Planned Development Amended
Source:	Jefferson County

Table 3-3 Summary of Current and Future Land Uses[a,b,c]

Land Use Category	Current		Future	
	Offsite	Onsite	Offsite	Onsite
Residential	Yes	No	Credible	Improbable
Commercial/Industrial	Yes	Yes	Credible	Credible[d]
Recreational	Yes	No	Credible	Plausible[e]
Ecological Reserve	No	No	Improbable	Credible[e]
Agricultural	Yes	No	Plausible	Improbable

[a] Credible is used to indicate scenarios that may reasonably occur.
[b] Plausible is used to indicate scenarios that are conceivable, though not expected.
[c] Improbable is used to indicate scenarios that are unlikely to occur.
[d] Expected in the currently developed area of the plant site.
[e] Expected in the buffer zone.

Table 3-4 Current and Future Land Use Scenarios Retained for Quantitative Evaluation

Land Use Category	Current		Future	
	Offsite	Onsite	Offsite	Onsite
Residential	Quantitative[a]	None[d]	None[f]	Quantitative[i]
Commercial/Industrial	None[b]	Quantitative[e]	None[g]	Quantitative[jk]
Recreational	None[b]	None[d]	None[g]	None[g]
Ecological Reserve	None[b]	None[d]	None[d]	Quantitative[j]
Agricultural	None[c]	None[d]	None[h]	None[d]

a This current exposure scenario exists and is retained for quantitative evaluation.

b This current exposure scenario is judged to be bounded by the exposure of an offsite resident on the basis of exposure frequency and duration and contact rates.

c Current offsite agricultural land use down wind of OU4 primarily consists of horse boarding operations and intermittent cattle grazing and is expected to bound potential exposures for the current offsite residential land use scenario.

d This land use category does not currently apply or is improbable in the future and thus is not quantitatively evaluated.

e This current scenario has low exposure potential, considering the comprehensive health and safety program at RFP, but is included for the sake of completeness.

f The current offsite residential exposure scenario is representative of the future offsite residential exposure potential.

g This future land use category is judged to be bounded by the exposure potential for other future onsite categories quantitatively evaluated on the basis of exposure frequency and duration and contact rates.

h Growth pressures of Front Range development on land and water resources and associated increasing costs indicate that future agricultural land use around RFP will diminish from current uses and thus need not be evaluated.

i This future land use scenario is improbable; however, it is retained for evaluation to ensure that the most conservative scenario is included in the evaluation.

j This future land use scenario is credible and is anticipated to have a high exposure potential based on exposure frequency and duration and contact rates.

k This scenario will include both a hypothetical long-term worker as well as a hypothetical short-term construction worker.

Table 4-1
Rocky Flats Plant OU4
Potentially Complete Exposure Pathways to be Quantitatively Evaluated

Potentially Exposed Receptor	Scenario	Potentially Complete Exposure Pathways
Onsite worker	Current	Inhalation of airborne particulates Incidental soil ingestion Direct dermal contact with organic compounds in surface soil Groundshine (direct contact)
Offsite resident	Current	Inhalation of airborne particulates Soil ingestion (following deposition of particulates) Dermal contact with surface soil (following deposition of particulates) Ingestion of vegetables (following deposition of particulates)
Hypothetical onsite worker	Future	Inhalation of indoor and outdoor VOCs Incidental soil ingestion Dermal contact with organic compounds in soil Groundshine (direct contact)
Hypothetical onsite ecological researcher	Future	Inhalation of airborne particulates Incidental soil ingestion Direct dermal contact with surface soil Groundshine (direct contact)
Hypothetical onsite resident	Future	Inhalation of airborne particulates Ingestion of vegetables (surface deposition of particulates and root uptake) Incidental soil ingestion Direct dermal contact with organic compounds in surface soil Groundshine (direct contact)
Hypothetical onsite construction worker	Future	Inhalation of airborne particulates Incidental soil ingestion Dermal contact with organic compounds in soil Groundshine (direct contact)

Table 5-1 Soil Ingestion, Current Onsite Worker

$$\text{Intake Factor} = \frac{IR \times FI \times ME \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	RME
IR	=	Ingestion rate (mg/day)[a]	50
FI	=	Fraction ingested from contaminated source[b]	0.5
ME	=	Matrix effect[c]	chemical-specific
EF	=	Exposure frequency (days/year)[d]	207
ED	=	Exposure duration (years)[e]	5
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	1,825
		Carcinogenic	25,550

[a] EPA (1991b)

[b] Based on 4-hours of exposure to site soils per 8-hour work day.

[c] The matrix effect describes the reduced availability due to adsorption of chemicals to soil compared to the same dose administered in solution. Therefore, the soil matrix has the effect of reducing the dose of a compound (Poiger and Schlatter 1980). These values are chemical-specific.

[d] EPA 1991b, adjusted for snowcover. Assumes exposure at the Solar Ponds Area 5 days per week, 50 weeks per year, but accounts for 60 days/year of snowcover, 5/7 of which are assumed to occur during the days where pond workers are onsite.

[e] Assumes ponds to be closed within 5 years.

Table 5-2 Inhalation of Particulates, Current Onsite Worker

$$\text{Intake Factor} = \frac{IR \times ET \times EF \times ED \times DF}{BW \times AT}$$

		Parameter	RME
IR	=	Inhalation rate (m^3/hr)[a]	0.83
ET	=	Exposure time (hours/day)[b]	4
EF	=	Exposure frequency (days/year)[c]	207
ED	=	Exposure duration (years)[d]	5
DF	=	Deposition factor[e]	0.25
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	1,825
		Carcinogenic	25,550

[a] This is equivalent to 20 m^3/day (EPA 1991b).

[b] The ET is based on 4 hours of exposure at the site per day.

[c] Assumes exposure at the Solar Ponds Area 5 days per week, 50 weeks per year, and accounts for 60 days/yr of snowcover, 5/7 of which are assumed to occur during days when pond workers are onsite.

[d] Assumes pond closure within 5 years.

[e] Twenty-five percent of inhaled particles are deposited and remain in the lung; it is assumed that all of the chemicals in that fraction are absorbed (MRI 1985).

Table 5-3 Dermal Contact with Organic Compounds in Surface Soil, Current Onsite Worker

$$\text{Intake Factor} = \frac{SA \times AB \times AF \times FC \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	RME
SA	=	Surface area (cm^2)[a]	2,910
AB	=	Absorption factor[b]	chemical-specific
AF	=	Adherence factor (mg/cm^2)[c]	0.6
FC	=	Fraction contacted from contaminated source[d]	0.5
EF	=	Exposure frequency (days/year)[f]	207
ED	=	Exposure duration (years)[e]	5
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	1,825
		Carcinogenic	25,550

[a] The RME surface area is equivalent to face, forearms, and hands, or 15 percent of total body surface (EPA 1989b).

[b] Absorption of metals from a soil matrix is negligible (EPA 1991a). The absorption factor for semivolatiles, volatiles, and other organics is likely to be lower than 100% and will be determined on a chemical-specific basis.

[c] This is a median value from the range (average to upper estimate) for soil adherence values recommended by EPA (EPA 1992b).

[d] Based on 4 hours of exposure to soil per 8-hour workday.

[e] Assumes pond closure within 5 years.

[f] Assumes exposure at the Solar Ponds Area 5 days per week, 50 weeks per year, and accounts for 60 days/yr of snowcover, 5/7 of which are assumed to occur during days when pond workers are onsite.

Table 5-4 External Irradiation (Groundshine), Current Onsite Worker

$$\text{Exposure Factor} = \frac{ET \times EF \times ED}{ET_B \times EF_B}$$

Parameter			RME
ET	=	Exposure time (hours/day)[a]	4
ET_B	=	Baseline exposure time (hours/day)[b]	24
ED	=	Exposure duration (years)[c]	5
EF	=	Exposure frequency (days/year)[d]	207
EF_B	=	Baseline exposure frequency (days/year)[e]	365

[a] The ET is based on 4 hours of exposure to site soils per 8-hour work day.

[b] Baseline exposure time from HEAST (EPA, 1992c).

[c] Based on continued use of the present ponds for a maximum of 5 years.

[d] Based on the current ponds worker schedule of 5 days/week, 50 weeks per year, and accounts for 60 days/yr of snowcover, 5/7 of which are assumed to occur during days when pond workers are on site.

[e] Baseline exposure frequency from HEAST (EPA, 1992c).

Table 5-5 Soil Ingestion, Hypothetical Future Onsite Worker

$$\text{Intake Factor} = \frac{IR \times FI \times ME \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	RME
IR	=	Ingestion rate (mg/day)[a]	50
FI	=	Fraction ingested from contaminated source[b]	0.125
ME	=	Matrix effect[c]	chemical-specific
EF	=	Exposure frequency (days/year)[d]	207
ED	=	Exposure duration (years)[a]	25
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	9,125
		Carcinogenic	25,550

a EPA 1991b.

b Based on 1-hour of exposure to site soil per 8-hour workday.

c The matrix effect describes the reduced availability due to adsorption of chemicals to soil compared to the same dose administered in solution. Therefore, the soil matrix has the effect of reducing the dose of a compound (Poiger and Schlatter 1980). These values are chemical-specific.

d EPA 1991b, adjusted for snowcover. Assumes the standard 250 days/year occupational exposure frequency, but accounts for 60 days/year of snowcover; 5/7 of which are assumed to occur during the work week.

Table 5-6 Inhalation of Particulates, Hypothetical Future Onsite Worker

$$\text{Intake Factor} = \frac{IR \times ET \times EF \times ED \times DF}{BW \times AT}$$

Parameter			RME
IR	=	Inhalation rate (m^3/hr)[a]	0.83
ET	=	Exposure time (hours/day)[b]	8
EF	=	Exposure frequency (days/year)[c,e]	207
ED	=	Exposure duration (years)[c]	25
DF	=	Deposition factor[d]	0.25
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	9,125
		Carcinogenic	25,550

[a] This is equivalent to 20m^3/day (EPA 1991b).

[b] The ET is based on an 8-hour workday.

[c] EPA 1991b.

[d] Twenty-five percent of inhaled particles are deposited and remain in the lung; it is assumed that all of the chemicals in that fraction are absorbed (MRI 1985).

[e] Assumes the standard 250 days/year occupational exposure frequency, but accounts for 60 days/year of snowcover, 5/7 of which are assumed to occur during the work week.

Table 5-7 Dermal Contact with Organic Compounds in Surface Soil
Hypothetical Future Onsite Worker

$$\text{Intake Factor} = \frac{SA \times AB \times AF \times FC \times EF \times ED \times CF}{BW \times AT}$$

Parameter			RME
SA	=	Surface area (cm^2)[a]	2,910
AB	=	Absorption factor[b]	chemical-specific
AF	=	Adherence factor (mg/cm^2)[c]	0.6
FC	=	Fraction contacted from contaminated source[d]	0.125
EF	=	Exposure frequency (days/year)[e,f]	207
ED	=	Exposure duration (years)[e]	25
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	9,125
		Carcinogenic	25,550

[a] The RME surface area is equivalent to face, forearms, and hands, or 15 percent of total body surface (EPA 1989b).

[b] Absorption of metals from a soil matrix is negligible (EPA 1991a). The absorption factor for semivolatiles, volatiles, and other organics is likely to be lower than 100% and will be determined on a chemical-specific basis.

[c] This is a median value from the range (average to upper estimate) for soil adherence values recommended by EPA (EPA 1992b).

[d] Based on 1 hour of exposure to soil per 8-hour workday.

[e] EPA 1991b.

[f] Assumes the standard 250 days/year occupational exposure frequency, but accounts for 60 days/year of snowcover; 5/7 of which are assumed to occur during the work week.

Table 5-8 External Irradiation (Groundshine), Hypothetical Future Onsite Worker

$$\text{Exposure Factor} = \frac{ET \times EF \times ED}{ET_B \times EF_B}$$

		Parameter	RME
ET	=	Exposure time (hours/day)[a]	8
ET_B	=	Baseline exposure time (hours/day)[b]	24
ED	=	Exposure duration (year)[c]	25
EF	=	Exposure frequency (days/year)[d]	207
EF_B	=	Baseline exposure frequency (day/year)[e]	365

[a] The ET is based on an 8-hour work day.

[b] Baseline exposure time from HEAST (EPA, 1992c).

[c] Human Health Evaluation Manual, Supplemental Guidance: "Standard Default Exposure Factors" (EPA 1991b).

[d] Assumes the standard 250 days/year occupational exposure frequency, but accounts for 60 days/year of snowcover, 5/7 of which are assumed to occur during the work week.

[e] Baseline exposure frequency from HEAST (EPA, 1992c).

Table 5-9 Soil Ingestion, Hypothetical Future Onsite Ecological Researcher

$$\text{Intake Factor} = \frac{IR \times FI \times ME \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	RME
IR	=	Ingestion rate (mg/day)[a]	50
FI	=	Fraction ingested from contaminated source[b]	.006
ME	=	Matrix effect[c]	chemical-specific
EF	=	Exposure frequency (days/year)[d]	80
ED	=	Exposure duration (years)[e]	7
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	2,555
		Carcinogenic	25,550

[a] EPA 1991b.

[b] The FI assumes that, while at RFP, the ecological researchers spend time at OU4 as a relative proportion of the area of OU4 to total area of the buffer zone.

[c] The matrix effect describes the reduced availability due to adsorption of chemicals to soil compared to the same dose administered in solution. Therefore, the soil matrix has the effect of reducing the intake of a compound (Poiger and Schlatter 1980). These values are chemical-specific.

[d] Equivalent to 5 days/week for 16 weeks each year (field season).

[e] Based on guidance provided by IAG members.

Table 5-10 Inhalation of Particulates, Hypothetical Future Onsite Ecological Researcher

$$\text{Intake Factor} = \frac{IR \times ET \times FC \times EF \times ED \times DF}{BW \times AT}$$

		Parameter	RME
IR	=	Inhalation rate (m^3/hr)[a]	0.83
ET	=	Exposure time (hours/day)[b]	8
FC	=	Fraction from Contaminated Source[c]	.006
EF	=	Exposure frequency (days/year)[d]	80
ED	=	Exposure duration (years)[e]	7
DF	=	Deposition factor [f]	0.25
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	2,555
		Carcinogenic	25,550

[a] This is equivalent to $20m^3$/day (EPA 1991b).

[b] The ET assumes an 8-hour workday.

[c] The FC assumes that, while at RFP, the ecological researchers spend time at OU4 as a relative proportion of the area of OU4 to the area of the entire buffer zone.

[d] Equivalent to 5 days/week for 16 weeks (field season).

[e] Based on guidance provided by IAG members.

[f] Twenty-five percent of inhaled particles are deposited and remain in the lung; it is assumed that all chemicals in that fraction are absorbed (MRI 1985).

Table 5-11 Dermal Contact with Surface Soil, Hypothetical Future Onsite Ecological Researcher

$$\text{Intake Factor} = \frac{SA \times AB \times AF \times FC \times EF \times ED \times CF}{BW \times AT}$$

Parameter			RME
SA	=	Surface area (cm^2)[a]	2,910
AB	=	Absorption factor[b]	chemical-specific
AF	=	Adherence factor (mg/cm^2)[c]	0.6
FC	=	Fraction contacted from contaminated source[d]	.006
EF	=	Exposure frequency (days/year)[e]	80
ED	=	Exposure duration (years)[f]	7
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	2,555
		Carcinogenic	25,550

[a] The RME surface area is equivalent to face, forearms, and hands, or 15 percent of total body surface (EPA 1989b).

[b] Absorption of metals from a soil matrix is negligible (EPA 1991a). The absorption factor for semivolatiles, volatiles, and other organics is likely to be lower than 100% and will be determined on a chemical-specific basis.

[c] This is a median value from the range (average to upper estimate) for soil adherence values recommended by EPA (EPA 1992b).

[d] The FC assumes that while at RFP, the ecological researchers spend time at OU4 as a relative proportion of the area of OU4 to the area of the entire buffer zone.

[e] Equivalent to 5 days/week for 16 weeks (field season).

[f] Based on guidance provided by IAG members.

Table 5-12 External Irradiation (Groundshine), Hypothetical Future Onsite Ecological Researcher

$$\text{Exposure Factor} = \frac{ET \times EF \times ED \times FE}{ET_B \times EF_B}$$

		Parameter	RME
ET	=	Exposure time (hours/day)[a]	8
ET_B	=	Baseline exposure time (hours/day)[b]	24
ED	=	Exposure duration (yr)[c]	7
EF	=	Exposure frequency (days/yr)[d]	80
EF_B	=	Baseline exposure frequency (day/yr)[e]	365
FE	=	Fraction exposed from contaminated surface[f]	.006

[a] The ET assumes an 8-hour work day.
[b] Baseline exposure time from HEAST (EPA, 1992c).
[c] Based on guidance provided by IAG members.
[d] Equivalent to 5 days/week for 16 weeks (field season).
[e] Baseline exposure frequency from HEAST (EPA,1992c).
[f] The FE assumes that while at RFP, the ecological researchers spend time at OU4 as a relative proportion of the area of OU4 to the area of the entire buffer zone.

Table 5-13 Soil Ingestion, Hypothetical Future Onsite Ecological Researcher

$$\text{Intake Factor} = \frac{IR \times FI \times ME \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	RME
IR	=	Ingestion rate (mg/day)[a]	50
FI	=	Fraction ingested from contaminated source[b]	.006
ME	=	Matrix effect[c]	chemical-specific
EF	=	Exposure frequency (days/year)[d]	80
ED	=	Exposure duration (years)[e]	1
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	2,555
		Carcinogenic	25,550

[a] EPA 1991b.

[b] The FI assumes that, while at RFP, the construction workers spend time at OU4 as a relative proportion of the area of OU4 to total area of the buffer zone.

[c] The matrix effect describes the reduced availability due to adsorption of chemicals to soil compared to the same dose administered in solution. Therefore, the soil matrix has the effect of reducing the intake of a compound (Poiger and Schlatter 1980). These values are chemical-specific.

[d] Equivalent to 5 days/week for 16 weeks each year (field season).

[e] Based on assumption that the worker will only be on-site for one year.

Table 5-14 Inhalation of Particulates, Hypothetical Future Onsite Construction Worker

$$\text{Intake Factor} = \frac{IR \times ET \times FC \times EF \times ED \times DF}{BW \times AT}$$

		Parameter	RME
IR	=	Inhalation rate (m^3/hr)[a]	0.83
ET	=	Exposure time (hours/day)[b]	8
FC	=	Fraction from Contaminated Source[c]	.006
EF	=	Exposure frequency (days/year)[d]	250
ED	=	Exposure duration (years)[e]	7
DF	=	Deposition factor [f]	0.25
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	2,555
		Carcinogenic	25,550

[a] This is equivalent to 20m^3/day (EPA 1991b).

[b] The ET assumes an 8-hour workday.

[c] The FC assumes that, while at RFP, the construction workers spend time at OU4 as a relative proportion of the area of OU4 to the area of the entire buffer zone.

[d] Equivalent to 5 days/week for 50 weeks (EPA, 1991b).

[e] Based on assumption that the worker will only be on-site for a maximum duration of sever years to represent potential subchronic exposure to the future site worker.

[f] Twenty-five percent of inhaled particles are deposited and remain in the lung; it is assumed that all chemicals in that fraction are absorbed (MRI 1985).

Table 5-15 Dermal Contact With Surface Soil, Hypothetical Future Onsite Construction Worker

$$\text{Intake Factor} = \frac{SA \times AB \times AF \times FC \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	RME
SA	=	Surface area (cm^2)[a]	2,910
AB	=	Absorption factor[b]	chemical-specific
AF	=	Adherence factor (mg/cm^2)[c]	0.6
FC	=	Fraction contacted from contaminated source[d]	.006
EF	=	Exposure frequency (days/year)[e]	250
ED	=	Exposure duration (years)[f]	7
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	2,555
		Carcinogenic	25,550

[a] The RME surface area is equivalent to face, forearms, and hands, or 15 percent of total body surface (EPA 1989b).

[b] Absorption of metals from a soil matrix is negligible (EPA 1991a). The absorption factor for semivolatiles, volatiles, and other organics is likely to be lower than 100% and will be determined on a chemical-specific basis.

[c] This is a median value from the range (average to upper estimate) for soil adherence values recommended by EPA (EPA 1992b).

[d] The FC assumes that while at RFP, the construction workers spend time at OU4 as a relative proportion of the area of OU4 to the area of the entire buffer zone.

[e] Equivalent to 5 days/week for 50 weeks (EPA, 1991b).

[f] Based on assumption that the worker will only be on-site for a maximum duration of seven years to represent potential subchronic exposure to the future site worker.

Table 5-16 External Irradiation (Groundshine), Hypothetical Future Onsite Construction Worker

$$\text{Exposure Factor} = \frac{ET \times EF \times ED \times FE}{ET_B \times EF_B}$$

		Parameter	RME
ET	=	Exposure time (hours/day)[a]	8
ET_B	=	Baseline exposure time (hours/day)[b]	24
ED	=	Exposure duration (yr)[c]	7
EF	=	Exposure frequency (days/yr)[d]	250
EF_B	=	Baseline exposure frequency (day/yr)[e]	365
FE	=	Fraction exposed from contaminated surface[f]	.006

[a] The ET assumes an 8-hour work day.
[b] Baseline exposure time from HEAST.
[c] Based on assumption that the worker will only be on-site for a maximum duration of seven years to represent potential subchronic exposure to the site worker.
[d] Equivalent to 5 days/week for 50 weeks (EPA, 1991b).
[e] Baseline exposure frequency from HEAST.
[f] The FE assumes that while at RFP, the construction workers spend time at OU4 as a relative proportion of the area of OU4 to the area of the entire buffer zone.

Table 5-17 Soil Ingestion, Hypothetical Future Onsite Resident (Adult and Child)[a]

$$\text{Intake Factor} = \frac{IR \times FI \times ME \times EF \times ED \times CF}{BW \times AT}$$

Parameter			RME Adult	RME Child
IR	=	Ingestion rate (mg/day)[b]	100	200
FI	=	Fraction ingested from contaminated source[c]	0.5	0.5
ME	=	Matrix effect[d]	chemical-specific	
EF	=	Exposure frequency (days/year)[b,e]	290	290
ED	=	Exposure duration (years)[b]	24	6
CF	=	Conversion factor (kg/mg)	10^{-6}	10^{-6}
BW	=	Body weight (kg)	70	15
AT	=	Averaging time (days)		
		Noncarcinogenic	8,760	2,190
		Carcinogenic	23,360	2,190

[a] The calculation of a 30-year residential exposure to soil is divided into two parts. First, a six-year exposure duration is evaluated for young children, and this accounts for the period of highest soil ingestion (200 mg/day) and lowest body weight (15 kg). Second, a 24-year exposure duration is assessed for older children and adults by using a lower soil ingestion rate (100 mg/day) and an adult body weight (70 kg). These two periods are then time-averaged (EPA 1991b).

[b] EPA-recommended value (1991b).

[c] The RME (FI) assumes that residents are in contact with contaminated soils 50 percent of their time at home.

[d] The matrix effect describes the reduced availability due to adsorption of chemicals to soil compared to the same dose administered in solution. Therefore, the soil matrix has the effect of reducing the intake of the compound. These values are chemical-specific.

[e] Adjusted for snowcover of 60 days per year.

Table 5-18 Ingestion of Homegrown Vegetables, Hypothetical Future Onsite Resident

$$\text{Intake Factor} = \frac{IR \times FI \times ME \times EF \times ED \times CF}{BW \times AT}$$

	Parameter	RME
IR:	Ingestion rate, vegetables (mg/day)[a]	200,000
FI:	Fraction ingested from contaminated source[b]	0.4
ME:	Matrix effect	chemical-specific
EF:	Exposure frequency (days/year)[c]	122
ED:	Exposure duration (years)	30
CF:	Conversion factor (kg/mg)	10^{-6}
BW:	Body weight (kg)	70
AT:	Averaging time (days)	
	Noncarcinogenic	10,950
	Carcinogenic	25,550

a This ingestion rate is based on the typical consumption value of vegetables (EPA, 1991b).

b "Reasonable worst case" proportion that is homegrown of 40% (EPA 1991b).

c Homegrown vegetable consumption assumed to occur every day during the four month harvest period (June-September).

Table 5-19 Inhalation of Particulates, Hypothetical Future Onsite Resident

$$\text{Intake Factor} = \frac{IR \times ET \times EF \times ED \times DF}{BW \times AT}$$

Parameter			RME
IR	=	Inhalation rate (m^3/hr)[a]	0.83
ET	=	Exposure time (hours/day)[b]	24
EF	=	Exposure frequency (days/year)[c,e]	290
ED	=	Exposure duration (years)[c]	30
DF	=	Deposition factor[d]	0.25
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	10,950
		Carcinogenic	25,550

a This is equivalent to 20 m^3/day (EPA 1991b).
b This RME exposure time assumes that 24 hours per day is spent at home.
c EPA 1991b.
d Twenty-five percent of inhaled particles are deposited and remain in the lung; it is assumed that all chemicals in that fraction are absorbed (MRI 1985).
e Adjusted for snowcover of 60 days per year.

Table 5-20 Dermal Contact with Organic Compounds in Surface Soil, Hypothetical Future Onsite Resident

$$\text{Intake Factor} = \frac{SA \times AB \times AF \times FC \times EF \times ED \times CF}{BW \times AT}$$

		Parameter	RME
SA	=	Surface area (cm^2)[a]	2,910
AB	=	Absorption factor[b]	chemical-specific
AF	=	Adherence factor (mg/cm^2)[c]	0.6
FC	=	Fraction contacted from contaminated source[d]	0.5
EF	=	Exposure frequency (days/year)[e]	290
ED	=	Exposure duration (years)[e]	30
CF	=	Conversion factor (kg/mg)	10^{-6}
BW	=	Body weight (kg)	70
AT	=	Averaging time (days)	
		Noncarcinogenic	10,950
		Carcinogenic	25,550

a The RME surface area is equivalent to face, forearms, and hands, or 15 percent of total body surface (EPA 1989b).

b Absorption of metals from a soil matrix is negligible (EPA 1991a). The absorption factor for semivolatiles, volatiles, and other organics is likely to be lower and will be determined on a chemical-specific basis.

c EPA 1992b.

d The FC assumes that residents are in contact with chemical-containing media 50 percent of their time at home.

e EPA 1991b, adjusted for snowcover of 60 days/year.

Table 5-21 External Irradiation (Groundshine), Hypothetical Future Onsite Resident

$$\text{Exposure Factor} = \frac{ET \times EF \times ED}{ET_B \times EF_B}$$

		Parameter	CRME
ET	=	Exposure time (hours/day)[a]	24
ET_B	=	Baseline exposure time (hours/day)[b]	24
ED	=	Exposure duration (yr)[c]	30
EF	=	Exposure frequency (days/yr)[c]	350
EF_B	=	Baseline exposure frequency (day/yr)[d]	365

[a] The RME exposure time assumes 24 hours per day are spent at home.
[b] Baseline exposure time from HEAST (EPA, 1992c).
[c] Human Health Evaluation Manual, Supplemental Guidance: "Standard Default Exposure Factors" (EPA 1991b).
[d] Baseline exposure frequency from HEAST (EPA, 1992c).

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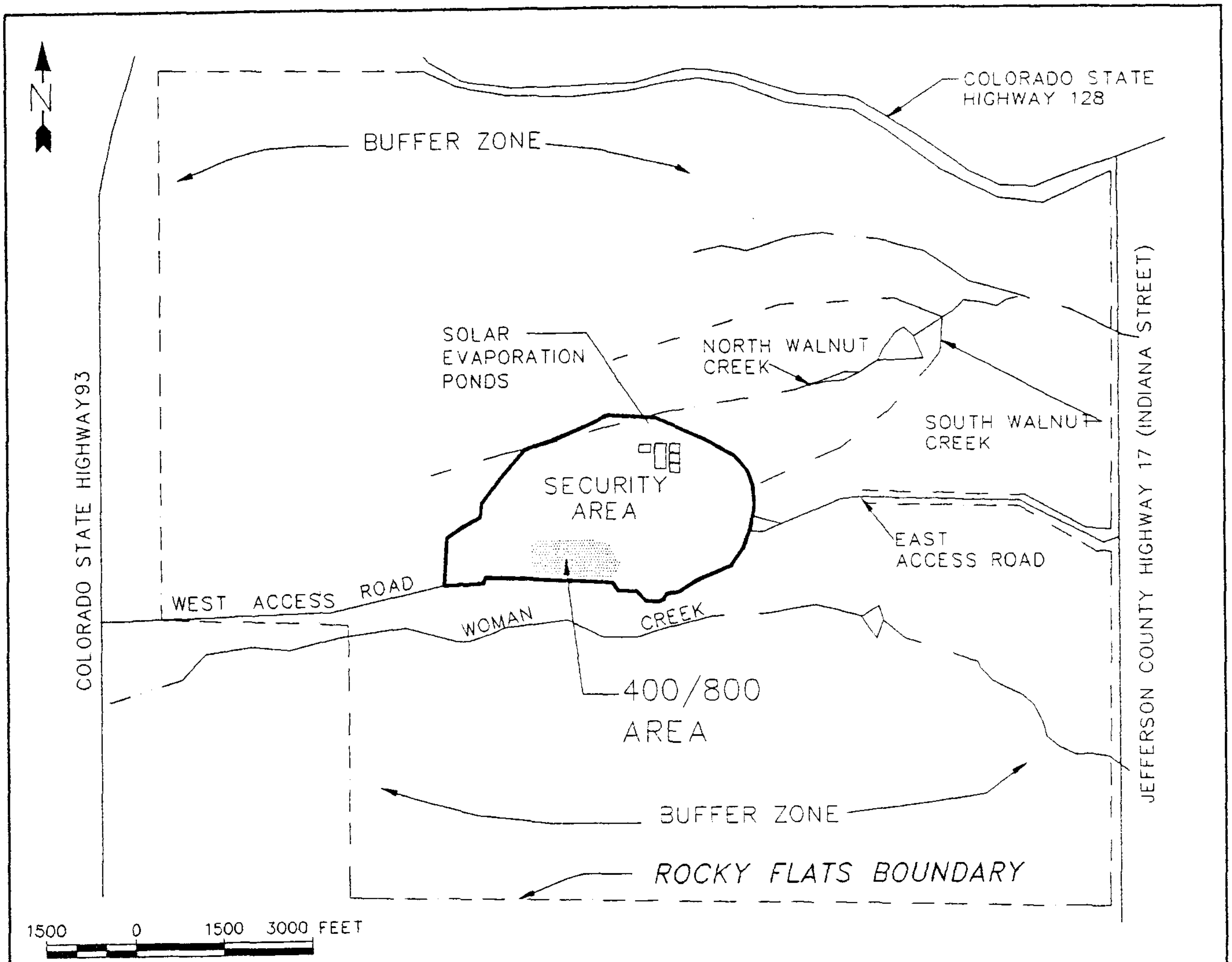

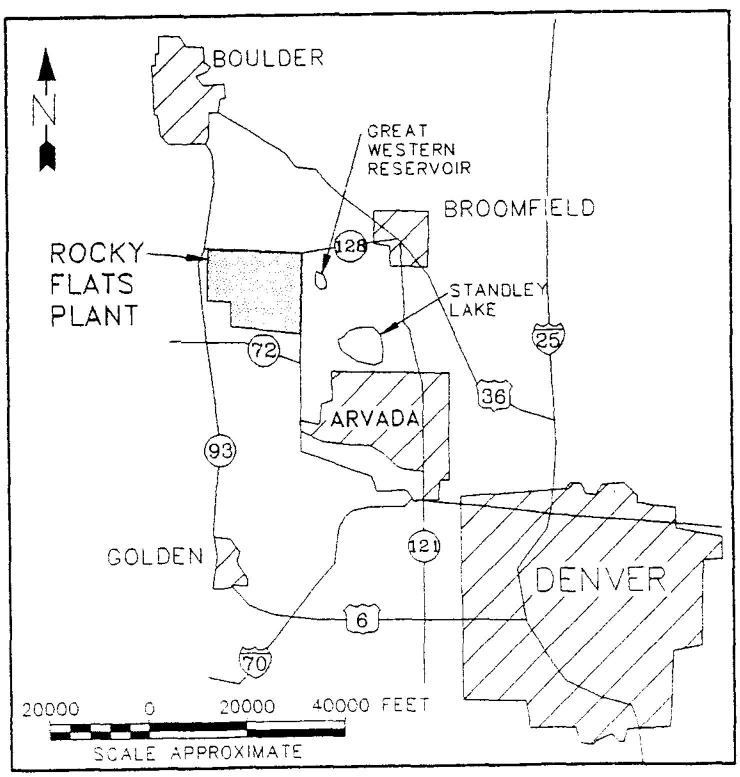

MODIFIED FROM: PHASE ONE RFI/RI WORK PLAN, OU9, EG&G 1992a

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FIGURE 2-1
ROCKY FLATS LOCATION MAP

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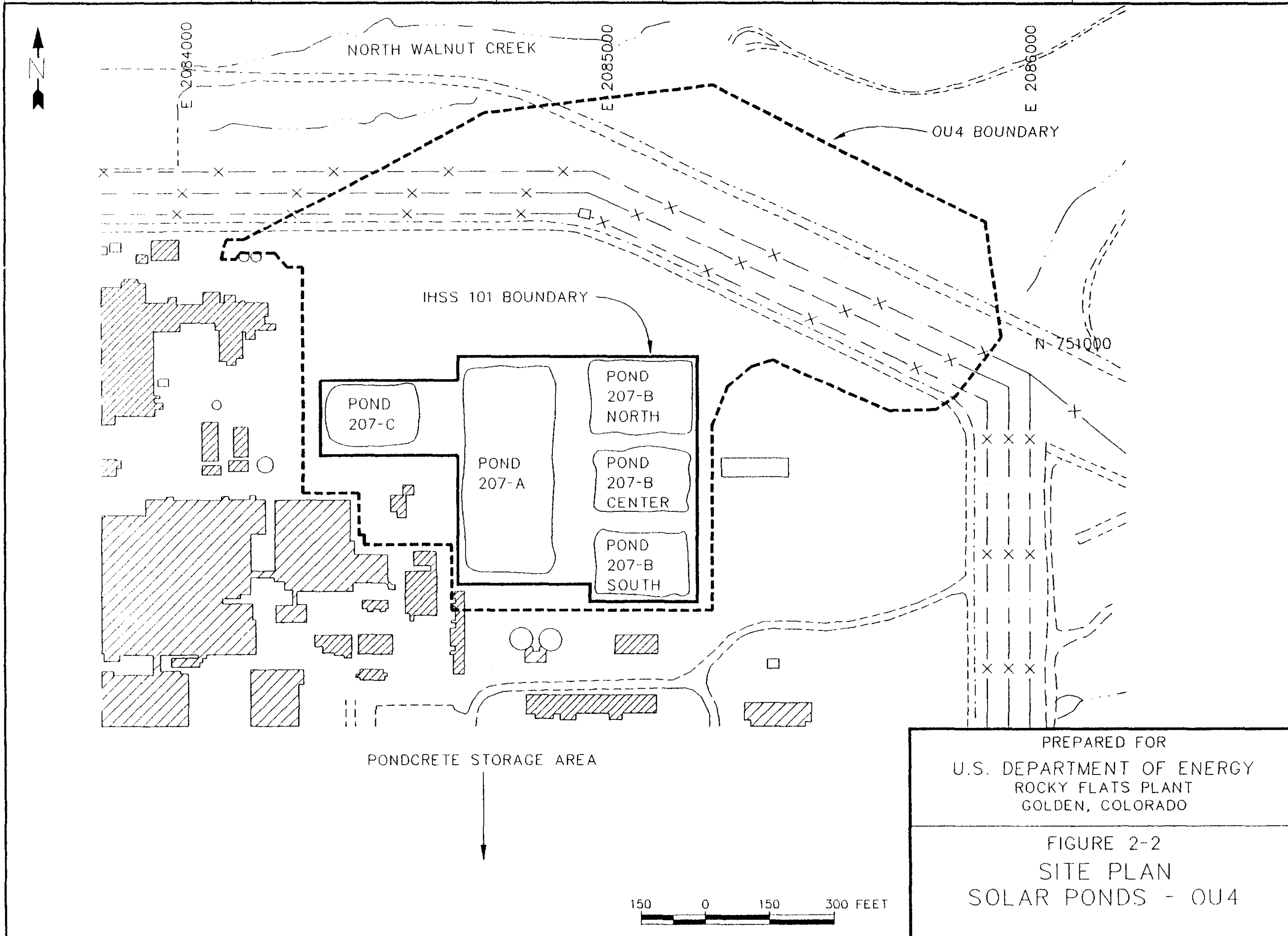

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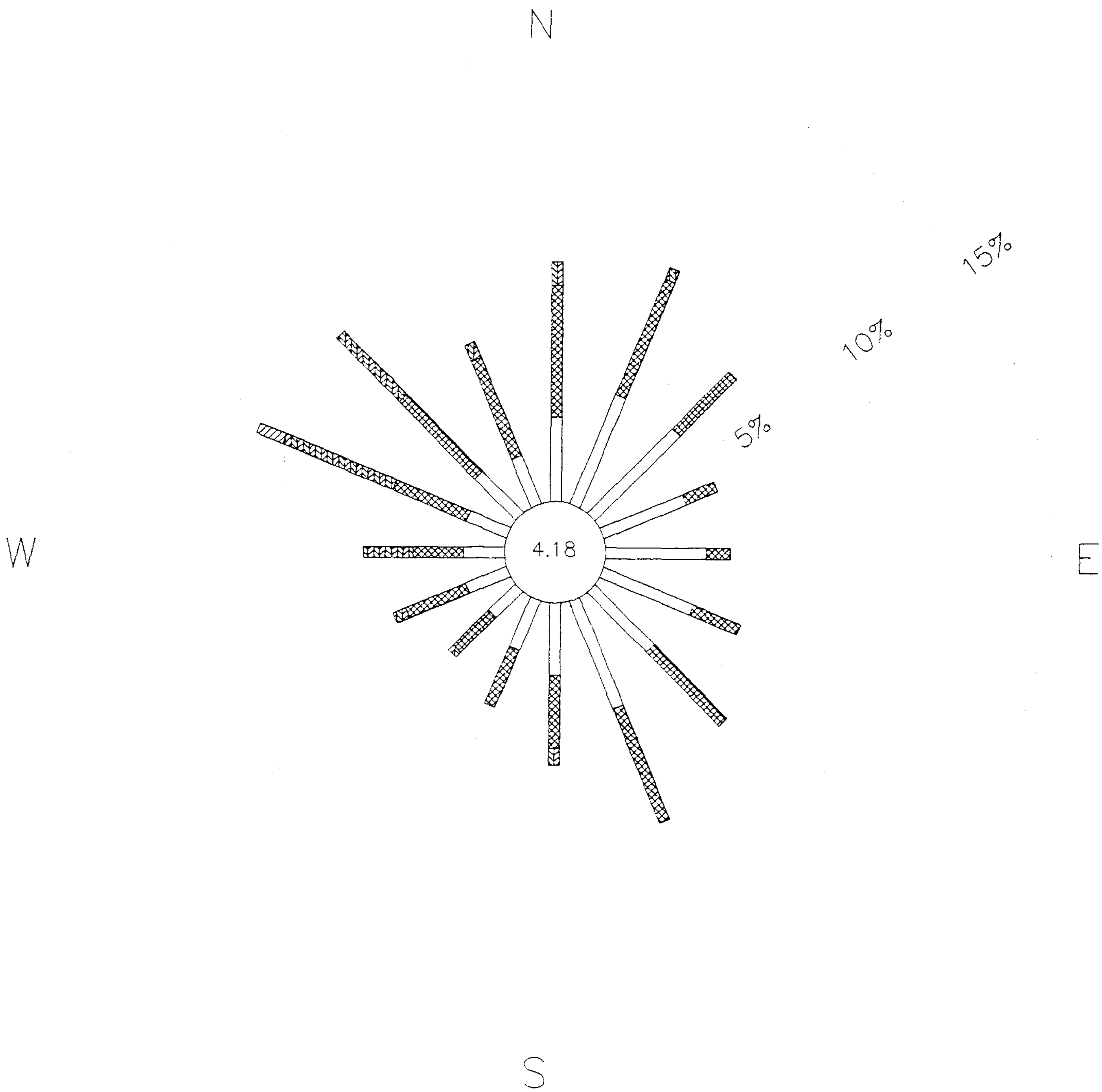
FIGURE 2-2
SITE PLAN
SOLAR PONDS - OU4



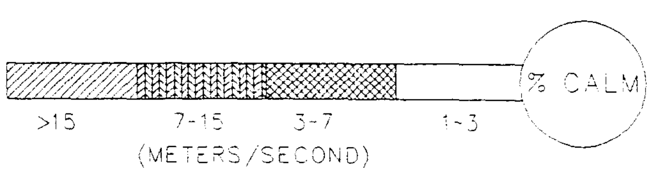


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FIGURE 2-3
WIND ROSE FOR RFP - 1990
0600-1900 MOUNTAIN
STANDARD TIME

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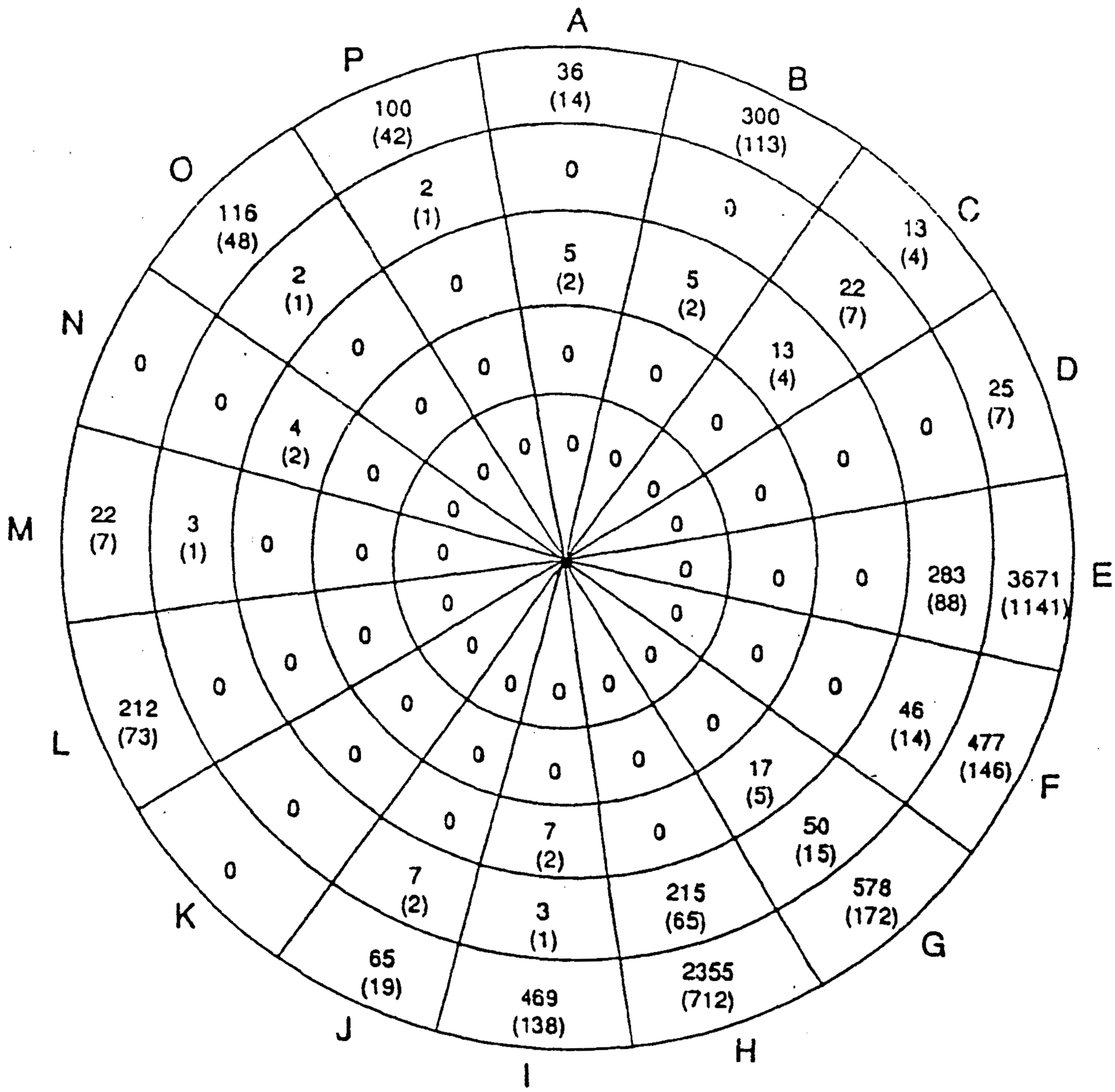

Miles	Sector Name
0-1	Sector 1
1-2	Sector 2
2-3	Sector 3
3-4	Sector 4
4-5	Sector 5

REFERENCE: DOE, 1989 POPULATION ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT (1991b)

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GOLDEN, COLORADO

FIGURE 3-1

1989 POPULATIONS AND (HOUSEHOLDS) SECTORS 1-5

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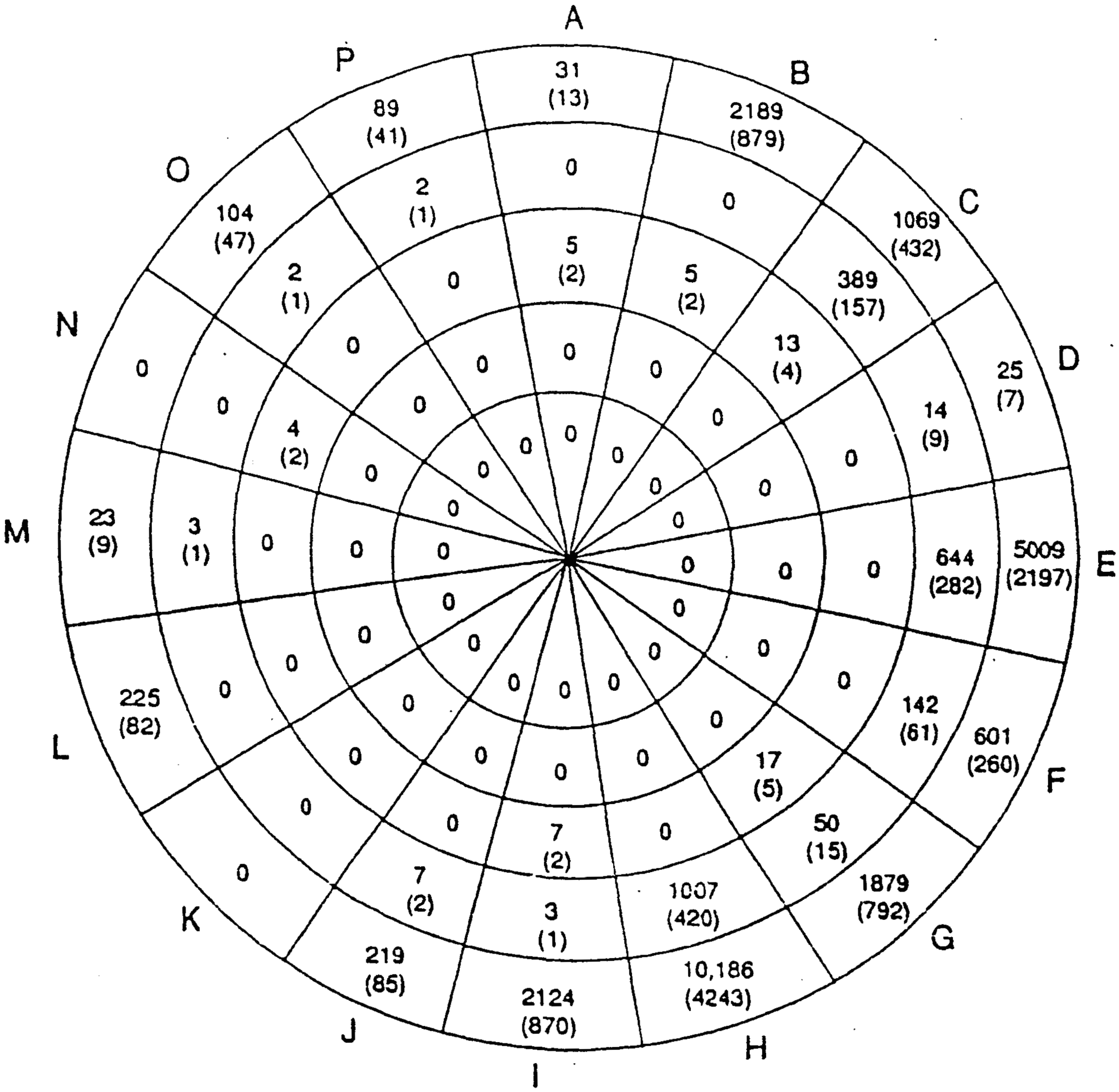

Miles	Sector Name
0-1	Sector 1
1-2	Sector 2
2-3	Sector 3
3-4	Sector 4
4-5	Sector 5

REFERENCE: DOE, 1989 POPULATION ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT (1991b)

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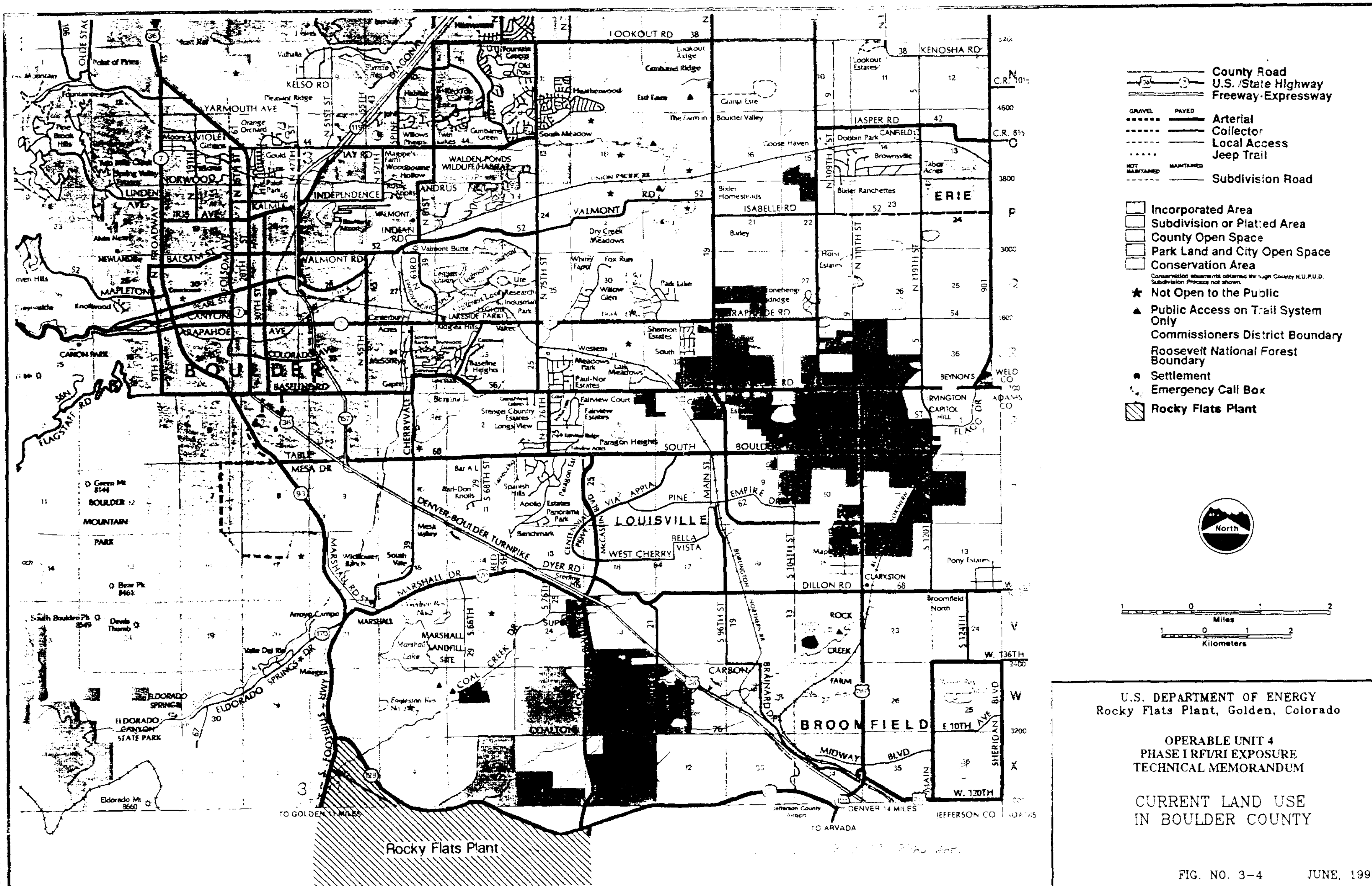
FIGURE 3-2

2010 ESTIMATED POPULATIONS AND (HOUSEHOLDS) SECTORS 1-5



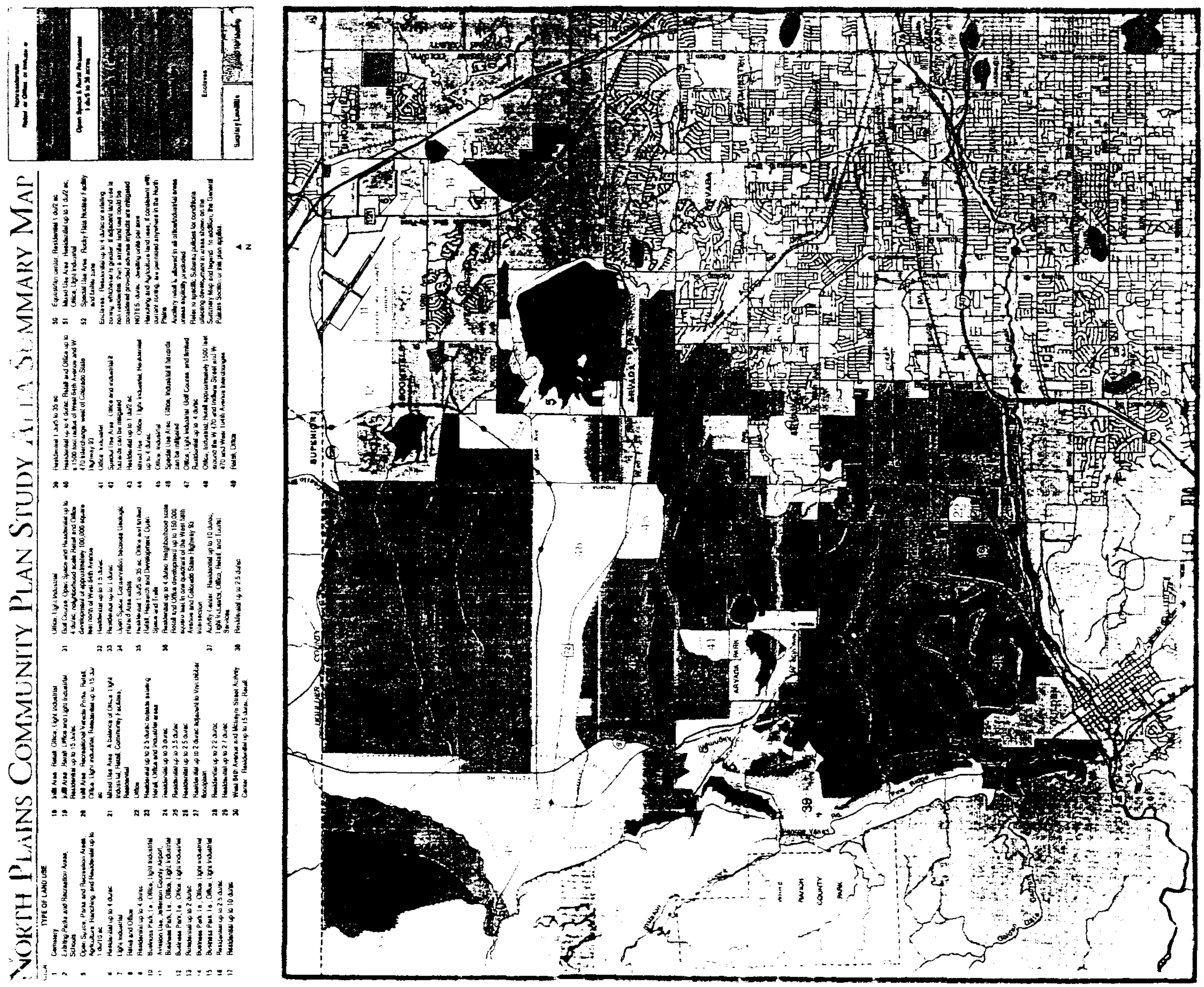
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT 4
PHASE I RFI/RI EXPOSURE
TECHNICAL MEMORANDUM

CURRENT LAND USE
IN BOULDER COUNTY

FIG. NO. 3-4 JUNE, 1992

2304703



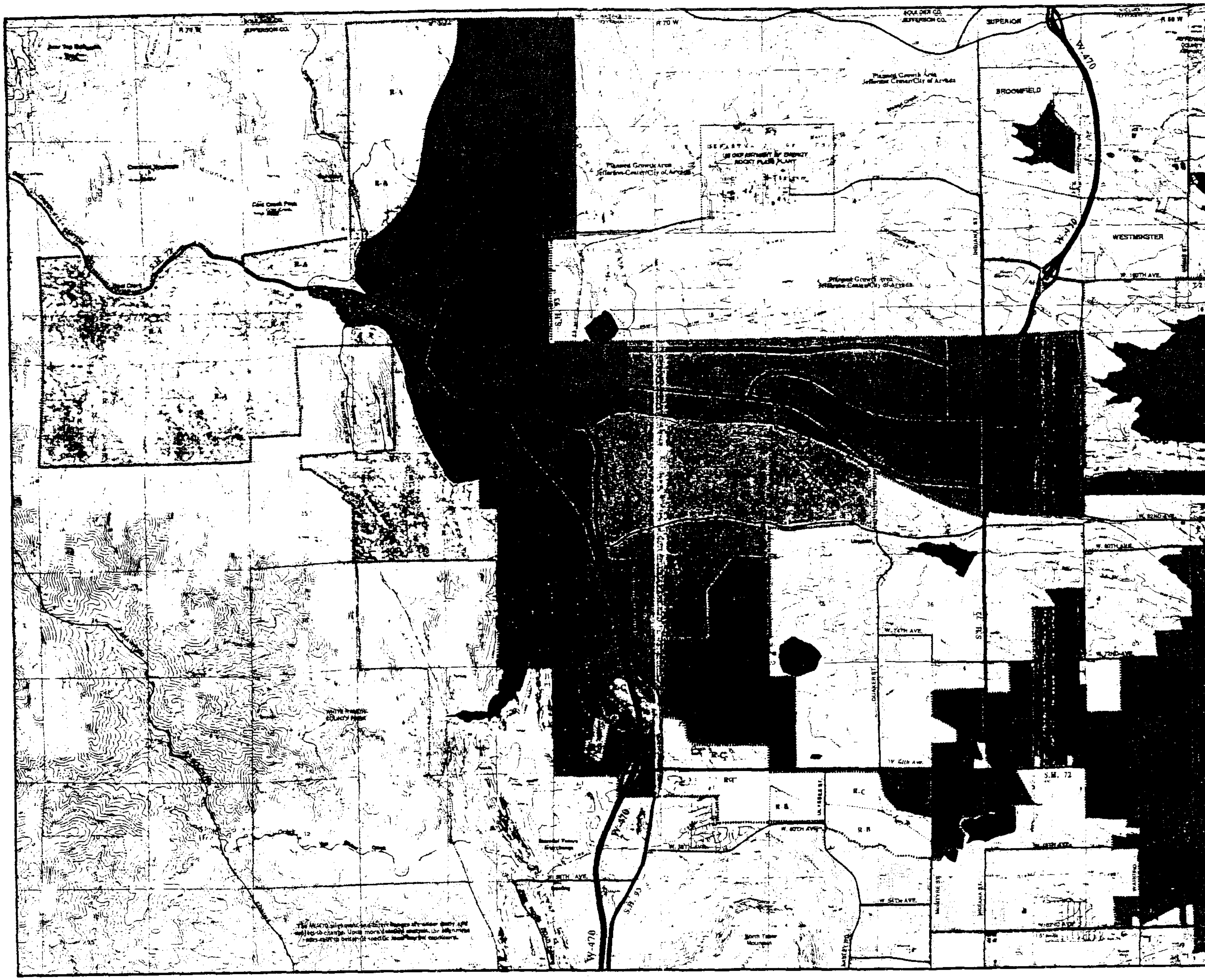
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT 4
PHASE I RFI/RI EXPOSURE
TECHNICAL MEMORANDUM

FUTURE LAND USE
IN JEFFERSON COUNTY

FIG. NO. 3-5 JUNE, 1992

2304/335



JEFFERSON COUNTY

City of Arvada

JCMD NO. 1

Jefferson Center Metropolitan District No. 1

Jefferson CENTER Associates

Jefferson Center Comprehensive Development Plan

FIGURE 3-6

Legend

- Commercial and Office
- Industrial and Office
- Mixed-Use: A B or C
- Residential (A, B or C)
- Agricultural
- Open Space
- Special Use
- W-470
- Arterial Roadways
- Collector Roadways
- Existing Roadways
- Jefferson Center Development Area

SOURCE: DOE 1992.

Approval

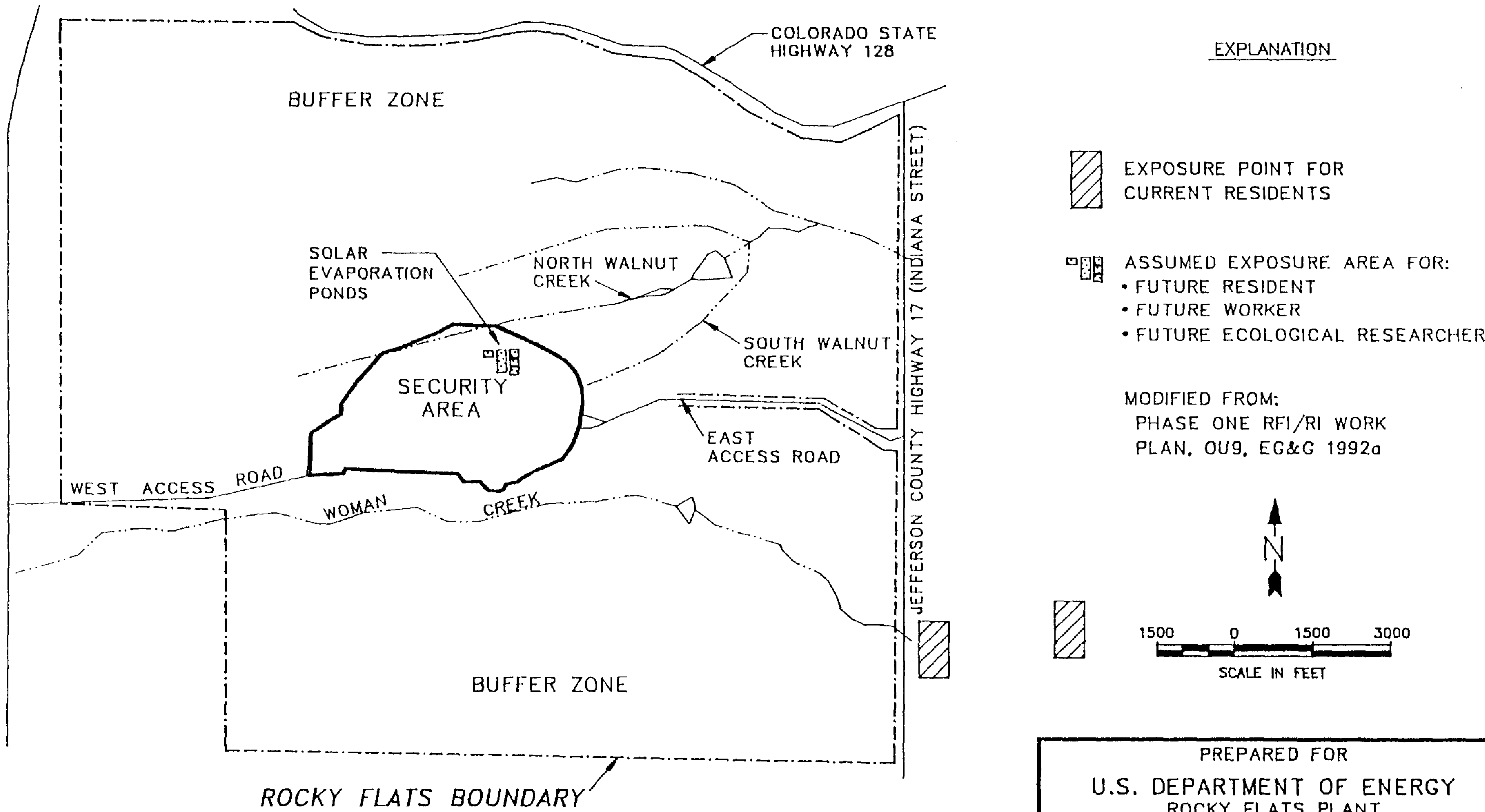
Jefferson County

City of Arvada

Vice President

NORTH

CHECKED BY	APPROVED BY	DRAWN BY BC	DATE 02/16/93	FILE NAME RECEPTOR.DWG	REVISION NO. 1



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ROCKY FLATS PLANT
GOLDEN, COLORADO

FIGURE 3-7

RECEPTOR LOCATIONS

APPENDIX A

APPENDIX A

PRELIMINARY ANALYSIS OF WORKER EXPOSURES TO CHEMICALS AND RADIONUCLIDES IN THE OU 4 SOLAR PONDS AREA

Introduction

This Appendix presents available data which may be used to evaluate exposures to current and future workers in the OU4 area. The objective of this preliminary assessment is to obtain a regulatory compliance perspective on current and potential future occupational risks. Statutory control of workplace risks falls under the jurisdiction of regulatory agencies such as OSHA and the Nuclear Regulatory Commission, rather than U.S. EPA Region VIII or the Colorado Department of Health. Risk management of occupational exposures is based on achieving compliance with established exposure standards.

The exposure point concentrations and dose equivalents presented in this Appendix are relevant to evaluating risks potentially associated with future uses of the Solar Ponds area. As stated in the main text of TM4, it is likely that the portions of the Rocky Flats Plant which are presently used for industrial purposes will retain that type of application in the future. Considering the industrialized setting of OU4, it is possible that the specialized technology, building structures and work force in this area would be candidates for future industrial ventures.

Analysis Method

The traditional occupational and radiological health standards and criteria approach was used for the assessment presented in this Appendix. This approach compares measured exposure levels (usually breathing zone concentrations) with established standards and criteria. The measurement methods are normally consensus approaches such as those prescribed by the National Institute of Occupational Health (NIOSH) or OSHA. The exposure criteria used for comparison were also developed by consensus and are considered to be protective of human health. For example, Threshold Limit Values (TLVs) established by the American Conference of Governmental Industrial Hygienists (ACGIH) "refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect" (ACGIH, 1989). The National Council on Radiation Protection and Measurements (NCRP) has used a similar concept to develop recommended limits for occupational exposure to radionuclides. NCRP occupational exposure limits are considered to be biased towards a greater acceptance of risk than OSHA or NIOSH exposure limits.

Potential Exposure to Airborne Plutonium in the Vicinity of the Solar Ponds and Adjacent Buffer Zone. Appendix A, Table I presents concentrations of plutonium-239 taken from continuous high-volume (Hi Vol) air samplers located in the vicinity of the Solar Ponds. These samplers are part of the RFP

Radioactive Ambient Air Monitoring Program (RAAMP). Most of the data displayed on Table II were collected in 1991 and 1992, with only two samples from 1990. Samplers S-01 and S-025 are located in the immediate vicinity of the ponds. Plutonium concentrations registered by these two continuously operating samplers are representative of concentrations in air inhaled by workers in the Solar Ponds area. Sampler S-4 is located in the buffer zone approximately 750 feet due north of the B-series ponds. Plutonium concentrations registered by this sampler are reflective of airborne concentrations which would be experienced by workers in the buffer zone portion of OU4. Figure A-1 illustrates the approximate location of these samplers.

Table II presents summary statistics for airborne plutonium concentrations detected by the three Hi Vol samplers located in the Solar Ponds area. The summary statistics presented in this table have been used to estimate plutonium doses experienced by workers in the Solar Ponds area. Doses were estimated by making conservative, although not worst-case exposure assumptions. Table III presents a summary of airborne plutonium effective dose equivalents (EDEs). The estimated effective dose equivalents presented in Table III can be compared to relevant and appropriate exposure criteria presented in Table IV. The average and 95% upper confidence limit estimates of EDE (mrem/yr) can be compared with: (1) the NCRP's 5 rem/year (5,000 mrem/yr) recommended exposure limit for radiation workers, and (2) NCRP's 0.5 rmem/year (500 mrem/yr) exposure limit for

APPENDIX A
TABLE I
PLUTONIUM-239 CONCENTRATION IN AMBIENT AIR FOR
SELECTED ON-SITE SAMPLERS

Site	Date	Number of Composited Monthly Samples	Volume (m^3)	Total Pu Conc. (pCi/m^3)	+/- 95% Confidence Interval (pCi/m^3)
s-01	11/90	No Sample Taken			
s-01	01/91	1	36076	.001957	.000347
s-01	02/91	1	35264	.000336	.000055
s-01	03/91	1	53665	.001194	.000172
s-01	04/91	1	12458	.004501	.000738
s-01	05/91	1	29489	.000667	.000103
s-01	06/91	1	8969	.000511	.000082
s-01	07/91	1	6448	.004177	.000722
s-01	08/91	1	2856	.009941	.001456
s-01	09/91	1	12220	.002202	.000297
s-01	10/91	1	10130	.000484	.000076
s-01	11/91	1	33996	.000156	.000031
s-01	12/91	1	3632	.001210	.000195
s-01	01/92	1	17705	.000183	.000033
s-01	02/92	1	15374	.000373	.000075
s-01	03/92	1	24269	.000192	.000040
s-01	05/92	1	13504	.000345	.000072
s-01	06/92	No Sample Taken			
s-01	09/92	1	7764	.002277	.000364
s-04	11/90	2	26776	.000014	.000009
s-04	01/91	1	24643	.000004	.000002
s-04	02/91	1	24343	.000002	.000004
s-04	03/91	1	37808	.000003	.000003
s-04	04/91	1	23577	.000003	.000004
s-04	05/91	1	24974	.000016	.000006
s-04	06/91	1	23034	.000010	.000004
s-04	07/91	1	19137	.000007	.000004

APPENDIX A
TABLE I (CONTINUED)
PLUTONIUM-239 CONCENTRATION IN AMBIENT AIR FOR
SELECTED ON-SITE SAMPLERS

Site	Date	Number of Composited Monthly Samples	Volume (m^3)	Total Pu Conc. (pCi/m^3)	+/- 95% Confidence Interval (pCi/m^3)
s-04	09/91	1	36430	.000019	.000004
s-04	10/91	1	26069	.000013	.000005
s-04	11/91	1	26740	.000004	.000003
s-04	12/91	1	27356	.000006	.000003
s-04	01/92	1	27547	.000002	.000002
s-04	02/92	1	28365	.000007	.000003
s-04	03/92	1	10860	.000010	.000005
s-04	05/92	No Sample Taken			
s-25	01/91	1	33789	.000231	.000044
s-25	02/91	1	32849	.000379	.000058
s-25	03/91	1	50385	.000079	.000012
s-25	04/91	1	14475	.000112	.000026
s-25	05/91	1	24262	.000055	.000013
s-25	06/91	1	26941	.000000	.000001
s-25	07/91	1	27270	.000066	.000015
s-25	08/91	1	31919	.000713	.000100
s-25	09/91	1	44571	.000041	.000008
s-25	10/91	1	27354	.000073	.000013
s-25	11/91	1	30093	.000041	.000009
s-25	12/91	1	22344	.000131	.000024
s-25	01/92	1	27918	.000036	.000007
s-25	02/92	1	24608	.000151	.000032
s-25	03/92	1	29516	.000045	.000011
s-25	05/92	1	20266	.000065	.000016
s-25	06/92	No Sample Taken			
s-25	09/92	1	25769	.000073	.000017

APPENDIX A
TABLE II
SUMMARY OF AIRBORNE PLUTONIUM CONCENTRATIONS FROM CONTINUOUS SAMPLERS IN OU4
PCI/METER^3

Statistical Parameter	S-01	S-25	Combined S-01 & S-25	S-04
No. Measurements	17	16	33	17
Range	0.000156 - 0.009941	0.000036 - 0.000713	0.00036 - 0.009941	2E-6 - 0.000019
Average	0.001806	0.000143	0.000999	8E-6
Geometric Mean	0.000875	0.000094	0.000297	6.3E-6
Standard Deviation	0.00249	0.000176	0.001956	5.4E-6
Coefficient of of Variation %	0.19	123	196	68
95% UCL	0.00286	0.00022	0.00158	1.04E-5

In general, data presented in Table II indicate:

- On average, airborne plutonium concentrations tend to be about ten times higher at S-1 than at S-25.

- Airborne plutonium concentrations at S-1 than at S-25 (near the ponds) to be about 100 times higher than those measured at S-4, which is in the buffer zone and comparatively distant from the ponds.

- The wide range in coefficients of variation [(standard deviation/average)*100] suggests considerable relative variability in airborne plutonium concentrations between samplers.

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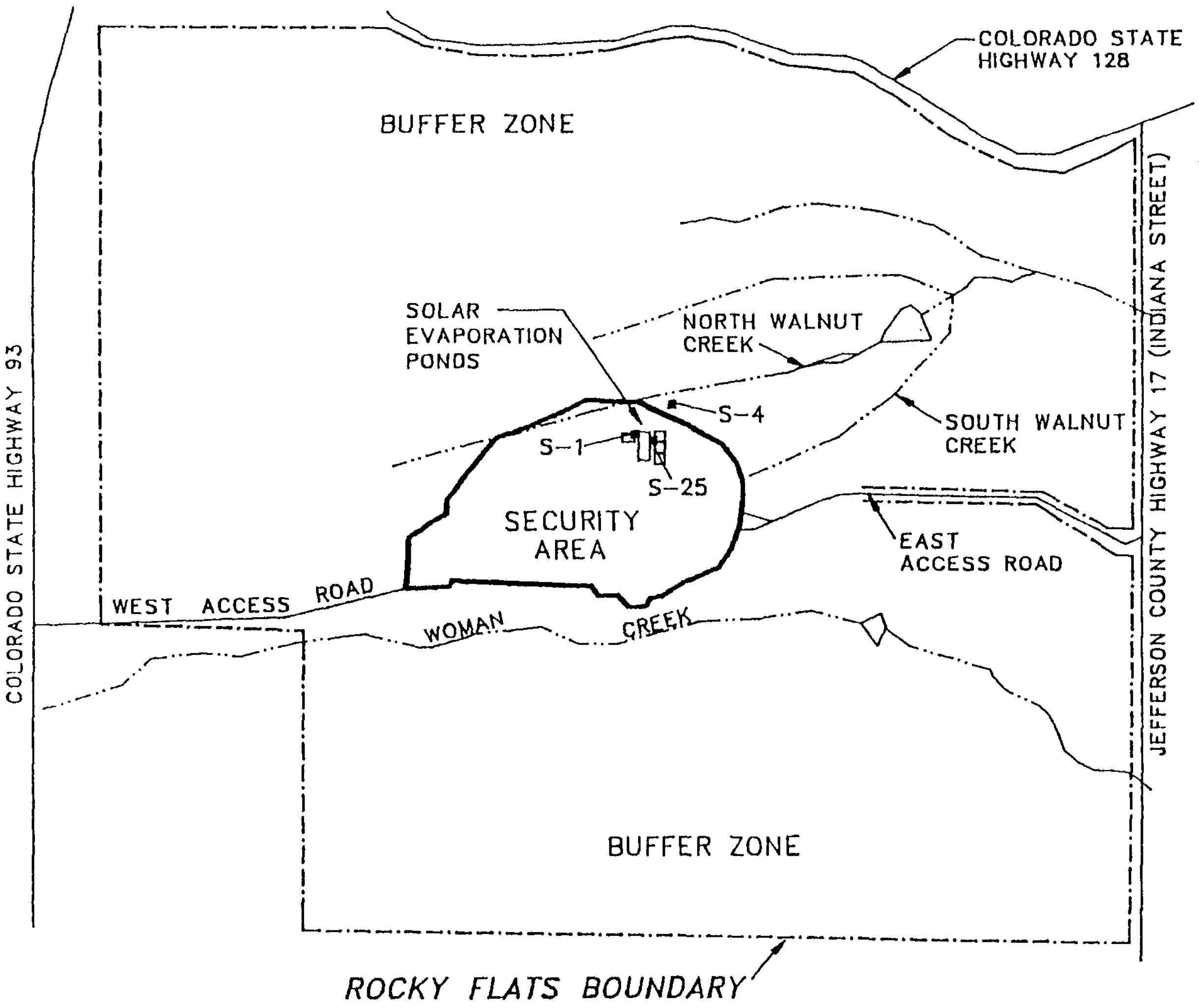

EXPLANATION

■ ONSITE AIR SAMPLERS

NOTE:
ALL SAMPLERS ANALYZED FOR PU

N

1500 0 1500 3000
SCALE IN FEET

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FIGURE A-1
ONSITE
AMBIENT AIR SAMPLERS

APPENDIX A
TABLE III
SUMMARY OF AIRBORNE PLUTONIUM
EFFECTIVE DOSE EQUIVALENTS
FROM SAMPLERS IN OU 4
MREM/YR (EDE)

	S-01	S-25	Combined S-01 & S-25	S-04
Average	1.39	0.11	0.77	6.2E-3
95% UCL	2.2	0.17	1.22	8.1E-3

Assumptions:

- Workers inhale 10 meter^3 air per work day.
- Workers work 250 days/year.
- Dose conversion factor for Pu^{239} is 8.33 E-5 Sv/Bq for 'Y Class" plutonium (EPA 1988).
- Workers are continuously exposed during working periods to the measured concentrations reflected in Table III.

APPENDIX A

TABLE IV

RELEVANT AND APPROPRIATE
EXPOSURE CRITERIA

Occupational	5 rem/yr	(5,000 mrem/yr)
Skin	15 rem/yr	(15,000 mrem/yr)
Hand	75 rem/yr	(75,000 mrem/yr)
Members of the Public	0.5 rem/yr	(500 mrem/yr)

Source: NCRP Report 91 (NCRP, 1987)

members of the general public. Estimated effective dose equivalents for workers in the Solar Ponds area are well below the NCRP recommended exposure limits for both workers and members of the general public. These comparisons may be interpreted as follows:

NCRP recognizes radiation workers as individuals working in an environment where there is significant potential for exposure to radionuclides. These workers are protected under risk management plans that include facets such as dosimetry, training, and work practices and procedures developed specifically for protecting workers from radiation hazards. NCRP recommends that exposures to workers like those in the Solar Ponds area not exceed 5 rem/year.

The EDEs presented in Table III suggest that the highest dose likely to be experienced by Solar Pond workers (S-01, 95% UCL of 2.2 mrem/yr) is approximately 1000 times less than the NCRP recommended exposure limit of 5000 mrem/yr.

NCRP also recognizes that "members of the public" includes all others except those directly involved with radionuclides. In essence, this implies that workers in a non radiation facility must be protected to a level of risk which is lower than that for radiation workers. The NCRP recommended EDE for members of the public should not exceed 500 mrem/yr including any doses received in the work place.

The estimated doses in Table III are approximately 100 times below the more conservative exposure limits for members of the general public.
Workers in the Solar Pond area, both radiological workers and "members of the public," are likely to be exposed to radionuclides such as americium and uranium, in addition to plutonium. The americium dose expected from ingrowth from secular equilibrium could theoretically produce an additional 20%. Although there appears to be a wide margin of safety between current (and future) estimated doses for both radiation workers and workers who are considered members of the public, there is clearly a great deal of uncertainty inherent in these estimates.

Other Potential Exposures to Radiation

In addition to inhaled doses of plutonium in air, workers may also be exposed to penetrating gamma radiation from radionuclides such as americium. Table V presents external dosimetry measurements for workers in the Solar Ponds area. The measurements were taken from January through December 1991. The range, mean, standard deviation, and 95% Upper Confidence Limit on the arithmetic mean are displayed at the bottom of page 3 of Table V. Estimated doses for penetrating gamma radiation are similar for the anatomical sites designated as Deep, Skin, and Hand.

In order to estimate the total annual dose that a worker in the Solar Ponds area may receive, the maximum estimated dose equivalent for plutonium of 2.2 mrem/yr can be added to the 95% UCL for the estimated Deep dose of penetrating gamma (56.78 mrem/yr) to give an estimated total dose of 58.98 mrem/yr. This probably represents the upper end of the dose range which would be experienced by a worker in the Solar Ponds area and is still below the recommendation for members of the general public.

Summary

The preliminary analysis of exposures presented in this Appendix is based on objectively measured indicators of exposure to chemicals and radionuclides in the OU4 area. The findings of this preliminary analysis suggests that workers in the Solar Ponds area are unlikely to experience exposures to either chemicals or radionuclides which exceed established occupational limits. There are uncertainties in estimating exposures to radionuclides other than plutonium. Site characterization has not yet been completed. From a regulatory compliance perspective, it appears unlikely that risks to workers would prevent future industrial use of OU4.

APPENDIX A
TABLE V
EXTERNAL DOSIMETRY
SUMMATION REPORTS

Individual Dose of Solar Pond Workers in Millrem: January through December 1992			
HS ID	DEEP	SKIN	HAND
443165	21	58	58
445084	32	32	32
448028	16	17	17
448032	10	35	35
448049	8	28	28
448279	11	18	18
448370	33	36	36
448371	17	17	17
448425	38	38	38
448467	0	7	7
448513	48	51	51
448514	7	7	7
448519	7	33	33
448524	20	31	31
448544	4	7	7
448545	13	13	13
448569	4	17	17
448570	19	20	20
448571	19	20	20
448572	17	25	25
448590	1	3	3
448592	21	33	33
448593	10	30	30
448594	30	16	16
448595	13	13	13
448596	3	16	16
448598	12	28	28
448599	10	12	12

APPENDIX A
TABLE V
EXTERNAL DOSIMETRY
SUMMATION REPORTS

Individual Dose of Solar Pond Workers in Millrem: January through December 1992			
HS ID	DEEP	SKIN	HAND
448602	5	1	1
448624	8	8	8
448626	6	6	6
448641	0	0	0
448643	0	0	0
448659	3	0	0
448660	3	0	0
448661	6	0	0
448662	0	12	12
448707	1	0	0
448708	5	9	9
448742	2	3	3
448743	2	3	3
448753	5	5	5
448767	7	10	10
511829	16	19	19
512669	9	28	28
513390	10	10	10
513618	15	22	199
513699	41	140	140
514247	16	53	53
515871	3	3	3
515885	15	29	29
515995	50	49	49
516057	41	50	50
516112	0	5	5
516115	52	61	61
516185	33	41	41

APPENDIX A
TABLE V
EXTERNAL DOSIMETRY
SUMMATION REPORTS

Individual Dose of Solar Pond Workers in Millrem: January through December 1992			
HS ID	DEEP	SKIN	HAND
516187	38	46	46
516190	9	12	12
516309	18	22	22
516334	18	32	32
516354	16	25	25
516372	7	10	10
516741	127	127	127
516571	12	12	12
516759	63	74	74
516777	50	52	52
516783	41	46	46
516788	6	10	10
516921	26	31	31
516923	20	28	28
516924	13	17	17
516925	3	10	10
516926	49	67	67
516928	9	16	16
517357	0	17	17
517391	20	86	86
518225	4	8	8

Range(0-127)(0-140)(0-199)

Mean17.4925.6627.96

Std. Dev.19.6425.9532.61

95% UCL56.7877.6093.18

APPENDIX B

APPENDIX B

TABLE I

PERSONAL BREATHING ZONE AIR SAMPLING SUMMARY

WATER AND SLUDGE SAMPLING AT 207 A-C SOLAR PONDS

May 13-23, 1991 and July 15-18, 1991

Agent	STD Ratio[1]	8-Hour TWA Standard[2] (mg/m³)	Range of Values			Total Personal Samples	Days Sampled Pond 207		
			207A	207B	207C		A	B	C
Acetone	<0.00006	1780	<0.10	0.0008-<0.1	<0.10-<0.11	19	1	5	3
Ammonia	<0.008	17	<0.12	<0.01-<0.12	<0.10-<0.13	22	1	6	3
Carbon Tetrachloride	<0.0016	12.6	<0.10	<0.20-<0.2	<0.10-<0.11	19	1	5	3
Ethyl Benzene	<0.0003	434	<0.10	<0.01-<0.1	<0.10-0.11	19	1	5	3
Methylene Chloride	<0.0006	174	<0.10	0.0004-<0.1	<0.10-<0.11	20	1	5	3
Methyl Ethyl Ketone	<0.0002	590	---	<0.01	<0.10	13	0	4	2
Methyl Isobutyl Ketone	<0.0005	205	<0.10	<0.01-<0.1	<0.10-<0.11	19	1	5	3
Non Polar Organics Scan	N/A	N/A	---	<0.05<0.32	---	13	0	6	0
Polar Organics Scan	N/A	N/A	<0.06	0.0004-<0.68	<0.05	24	1	7	3
1, 1, 2, 2-Tetrachloroethane	<0.016	6.9	<0.10	<0.01	<0.10-<0.11	17	1	4	3
Tetrachloroethene	<0.0006	170	<0.10	<0.01-<0.1	<0.10-<0.11	19	1	5	3
Toluene	<0.0003	375	<0.10	<0.01-<0.1	<0.10-<0.11	19	1	5	3
Trichloroethylene	<0.0004	269	---	<0.01	<0.10	13	0	4	2
TOTAL	N/A	N/A		0.0004-<0.68		236	1	7	3

NOTES:

[1] = Standard ratio refers to the ratio of 8-hour time-weighted average to the permissible exposure level. Standard ratios greater than 1.0 would indicate an exposure above the established standard. Standard ratios less than 0.5 indicate exposures less than 1/2 the established standard.

[2] = Standard refers to the most stringent published by the Occupational Safety and Health Administration (OSHA) or the American Conference of Governmental Industrial Hygienists (ACGIH).

APPENDIX B
TABLE II
REPRESENTATIVE BREATHING ZONE AIR SAMPLING SUMMARY
PONDCRETE OPERATIONS
FEBRUARY, 1990

Material Sampled	8-Hour TWA Standard/ Guideline (mg/m^3)	STEL/Ceiling (mg/m^3)	Range of Values (mg/m^3)	Building	People Samples	Days Sampled	Total Samples
Toluene	375 (1)	---	LT 2 - 6	788 750	4 6	2 3	6 6
Toluene	---	560(1)(S)	LT 4	788 750	7 6	4 3	22 22
Carbon tetrachloride	12.6(1)	NA	LT 3 - LT 9	788 750	4 6	2 3	6 6
Ethyl benzene	434 (2)	---	LT 2 - LT 5	788 750	4 6	2 3	6 6
Acetone	1780 (2)	---	LT 7 - LT 30	788 750	4 6	2 3	6 6
Acetone	---	2380 (2)(S)	LT 20	788 750	7 6	4 3	22 22
Methylene chloride	174 (2)	NA	LT 2 - LT5	788 750	4 6	2 3	6 6
1,1,2,2-tetrachloro-ethane	6.9 (2)	NA	LT 1 - LT 2	788 750	4 5	2 2	7 6
Ammonia (area only)	17 (2)	---	LT 0.6 - 8	788 750	4 3	2 2	6 6
Respirable dust	5 (1)	NA	LT 0.3 - LT 2	788 750	4 4	2 2	6 4
Unknown polar org. (areas and personals	NA	NA	ND	788 750	4 6	2 3	6 8
Hydrogen cyanide (area only)	NA	11 (1)(C)	LT 0.5 - LT 0.7	788 750	6 4	5 2	12 9
Aluminum	10 (2)	NA	LT 0.006 - LT 0.02	788 750	4 6	2 2	6 6

APPENDIX B
TABLE II
REPRESENTATIVE BREATHING ZONE AIR SAMPLING SUMMARY
PONDCRETE OPERATIONS
FEBRUARY, 1990

Material Sampled	8-Hour TWA Standard/ Guideline (mg/m^3)	STEL/Ceiling (mg/m^3)	Range of Values (mg/m^3)	Building	People Samples	Days Sampled	Total Samples
Antimony	0.5 (1)(2)	NA	LT 0.03 - LT 0.01	788 750	4 6	2 2	6 6
Arsenic	0.01 (1)	NA	LT 0.003 - LT 0.007	788 750	4 6	2 2	6 6
Barium	0.5 (1)(2)	NA	LT 0.003 - LT 0.007	788 750	4 6	2 2	6 6
Beryllium	0.002 (1)	NA	LT 0.002 - LT 0.004	788 750	4 6	2 2	6 6
Cadmium	0.05 (2)	0.05 (2)(C)	LT 0.003 - LT 0.02	788 750	7 6	4 3	26 24
Chromium	0.5 (1)(2)	NA	LT 0.006 - LT 0.02	788 750	4 6	2 2	6 6
Cobalt	0.05 (1)(2)	NA	LT 0.006 - LT 0.02	788 750	4 4	2 2	6 6
Copper	1 (1)(2)	NA	LT 0.006 - LT 0.02	788 750	4 6	2 2	6 6
Iron	5 (2)	NA	0.008 - 0.03	788 750	4 6	2 2	6 6
Lead	0.05 (2)	NA	LT 0.003 - LT 0.007	788 750	4 6	2 2	6 6
Magnesium	10 (1)(2)	NA	LT 0.006 - LT 0.02	788 750	4 6	2 2	6 6
Manganese	5 (2)	NA	LT 0.003 - LT 0.007	788 750	4 6	2 2	6 6
Molybdenum	10 (1)	NA	LT 0.003 - LT 0.007	788 750	4 6	2 2	6 6

APPENDIX B
TABLE II
REPRESENTATIVE BREATHING ZONE AIR SAMPLING SUMMARY
PONDCRETE OPERATIONS
FEBRUARY, 1990

Material Sampled	8-Hour TWA Standard/ Guideline (mg/m^3)	STEL/Ceiling (mg/m^3)	Range of Values (mg/m^3)	Building	People Samples	Days Sampled	Total Samples
Nickel	1 (1)	NA	LT 0.006 - LT 0.02	788 750	4 6	2 2	6 6
Selenium	0.2 (1)(2)	NA	LT 0.006 - LT 0.02	788 750	4 6	2 2	6 6
Silver	0.01 (1)	NA	LT 0.006 - LT 0.02	788 750	4 6	2 2	6 6
Thallium	0.1 (1)(2)	NA	LT 0.005 - LT 0.03	788 750	4 6	2 2	6 6
Tin	2 (1)(2)	NA	LT 0.003 - LT 0.007	788 750	4 6	2 2	6 6
Titanium (as titanium dioxide)	10 (1)(2)	NA	LT 0.006 - LT 0.02	788 750	4 6	2 2	6 6
Vanadium	0.05 (1)(2)	NA	LT 0.006 - LT 0.02	788 750	4 6	2 2	6 6
Zinc	10 (1)(2)	NA	LT 0.006 - LT 0.02	788 750	4 6	2 2	6 6

(1) = Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit
(2) = American Conference of Governmental and Industrial Hygienists (ACGIH) Threshold
(C) = Ceiling
(S) = Short Term Exposure Limit (STEL)
mg/m^3 = milligrams per cubic meter
NA = Not Applicable (no OSHA PEL or ACGIH TLV)

APPENDIX B
TABLE III
PERSONAL BREATHING ZONE AIR SAMPLING SUMMARY
PONDCRETE PUCK REPROCESSING OPERATIONS[1]
904 PAD, TENT 10 PERMACON
April 19, 1990 through December 11, 1990

Materials Sampled	8-Hour TWA Standard[2] (mg/m^3)	STEL/Ceiling	Range of Values (mg/m^3)	People Sampled	Days Sampled	Total Samples
Acetone	1780.0	---	<0.54- <7.0	12	6	13
Acetone	---	2380.0	<4.0	4	2	12
Aluminum	10.0	---	<0.002- 0.02	8	4	8
Ammonia	17.0	---	<0.01- <4.0	6	4	6
Ammonia	---	24.0	<0.02- <4.0	6	2	12
Antimony	0.5	---	<0.009- <0.02	4	2	4
Arsenic	0.01	---	<0.0003- <0.002	7	4	7
Barium	0.5	---	<0.0009- <0.0002	4	2	4
Beryllium	0.002	---	<0.00004- 0.0003	9	4	9
Beryllium	---	0.005	<0.0009- 0.001	5	2	10
Cadmium	0.05	---	<0.0006- 0.002	8	3	8
Cadmium	---	0.6	<0.005- 0.01	5	2	10
Calcium (as calcium silicate)	10.0	---	0.020 - 0.36	7	3	7
Carbon tetrachloride	12.6	---	<0.12- <9.0	10	5	11
Chromium	0.05	---	<0.002- 0.008	9	4	9
Cobalt	0.05	---	<0.002- <0.003	9	4	9
Copper	1.0	---	<0.002- <0.003	7	4	7
Cristobalite	0.05	---	<0.03- <0.08	5	3	5
O-Dichlorobenzene	---	300.0	<4.0- <20.0	6	2	12
Dioctyl phlalate	N/A	N/A	<0.06- <0.07	2	1	2
Dust, respirable	5.0	---	<0.1- 0.76	6	4	6

APPENDIX B
TABLE III
PERSONAL BREATHING ZONE AIR SAMPLING SUMMARY
PONDCRETE PUCK REPROCESSING OPERATIONS[1]
904 PAD, TENT 10 PERMACON
April 19, 1990 through December 11, 1990

Materials Sampled	8-Hour TWA Standard[2] (mg/m^3)	STEL/Ceiling	Range of Values (mg/m^3)	People Sampled	Days Sampled	Total Samples
Dust, total	15.0	---	<0.4- 0.63	2	1	2
Ethyl benzene	434.0	---	<0.15- .05	9	4	10
Ethyl benzene	---	543.0	<4.0	6	2	12
Iron	1.0	---	<0.0005- 0.054	10	5	10
Lead	0.05	---	<0.0009- <0.006	8	3	8
Lithium (as lithium hydride)	0.025	---	<0.0009- <0.002	4	2	4
Magnesium	10.0	---	0.0002 - 0.028	10	5	10
Manganese	5.0	---	<0.0009- <0.002	7	4	7
Manganese	---	5.0	<0.007- <0.007	5	2	10
Methylene chloride	174.0	---	<0.12- 0.8	8	4	8
Methylene chloride	---	2000.0	<4.0- <20.0	6	2	12
Methyi isobutyl ketone	205.0	---	<0.12- <2.0	8	4	8
Molybdenum	5.0	---	<0.0009- <0.002	4	2	4
Nickel	1.0	---	<0.002- <0.003	9	4	9
Nitrogen dioxide	5.6	---	<0.07- 0.14	5	2	5
Nitrogen dioxide	---	1.8	<0.001- 0.3	6	2	12
Nitromethane	50.0	---	<2.0- <5.43	3	2	3
Phosphorus	0.1	---	<0.003- 0.01	4	2	4
Polar organics scan	N/A	N/A	<0.001- 0.73	5	3	5
Quartz	0.1	---	<0.03- <0.08	6	4	6
Selenium	0.39	---	<0.002- <0.003	4	2	4

APPENDIX B

TABLE III

PERSONAL BREATHING ZONE AIR SAMPLING SUMMARY

PONDCRETE PUCK REPROCESSING OPERATIONS[1]

904 PAD, TENT 10 PERMACON

April 19, 1990 through December 11, 1990

Materials Sampled	8-Hour TWA Standard[2] (mg/m^3)	STEL/Ceiling	Range of Values (mg/m^3)	People Sampled	Days Sampled	Total Samples
Silver	0.01	---	<0.002- <0.003	6	3	6
Sodium (as sodium bisulfite)	5.0	---	<0.09- 0.2	4	2	4
1,1,2,2- Tetrachloroethane	6.9	---	<0.12- <0.5	7	4	7
Tetrachloroethylene (perchloroethylene)	170.0	---	<0.12- <2.0	8	4	9
Thallium	0.1	---	<0.005- 0.008	4	2	4
Tin	2.0	---	<0.009- <0.002	4	2	4
Titanium	10.0	---	<0.002- <0.003	4	2	4
1,1,1 Trichloroethane	1900.0	---	<0.4	1	1	1
Toluene	375.0	---	0.007 - <4.0	12	6	13
Toluene	---	560.0	<4.0	6	2	12
Vanadium	0.05	---	<0.002- <0.02	9	4	9
Xylene	434.0	---	0.037 - 0.167	2	1	2
Zinc	5.0	---	0.002 - 0.033	6	3	6
Zinc	---	2.0	0.002 - 0.033	5	2	10

NOTES:

1 = Pondcrete puck reprocessing included: reprocessing of failed pucks, test reprocessing runs with portland cement and soil, cleaning of reprocessing equipment, core sampling pucks, and mixing samples under Tent #10 laboratory hood.

2 = Standard refers to the most stringent standard published by the Occupational Safety and Health Administration (SHA) or the American Conference of Governmental Industrial Hygienist (ACGIH).

mg/m^3 = milligrams per cubic meter

APPENDIX B
TABLE IV
AREA AIR SAMPLING SUMMARY
PONDCRETE PUCK REPROCESSING OPERATIONS[1]
904 PAD, TENT 10 PERMACON
April 19, 1990 through December 11, 1990

Material Sampled	8-Hour TWA Standard[2] (mg/m^3)	STEL/Ceiling (mg/m^3)	Range of Values (mg/m^3)	Date	Total Samples
Ammonia	---	24.0	1.4 - 3.5	09/17/90	3
Ammonia	---	24.0	1.4 - 7.6	09/24/90	4
Ammonia	---	24.0	3.5 - 10.4	10/01/90	4
Hydrogen cyanide	---	5.0	<1.0	08/27/90	2
Hydrogen cyanide	---	5.0	<2.2	09/17/90	3
Hydrogen cyanide	---	5.0	<2.2	09/24/90	1
Hydrogen cyanide	---	5.0	<2.2	10/01/90	3
Nitric acid	---	10.0	<2.6	09/24/90	1
Nitrogen dioxide	---	1.8	<0.9	09/24/90	1

NOTES

[1] = Pondcrete puck reprocessing included: reprocessing of failed pucks, test reprocessing runs with portland cement and soil, cleaning of reprocessing equipment, core sampling pucks, and mixing samples under Tent #10 laboratory hood.

[2] = Standard refers to the most stringent standard published by the Occupational Safety and Health Administration (OSHA) or the American Conference of Governmental Industrial Hygienists (ACGIH).

mg/m^3 = milligrams per cubic meter

APPENDIX B
TABLE V
REAL TIME MONITORING DATA
WATER AND SLUDGE SAMPLING AT 207A-C SOLAR PONDS
May 13-23, 1991[1]

Date	Activity	Agent	Level (in ppm)	Standard[2] (in ppm)
05/13/91	207B Water sample preparation	Volatile Organic Compounds Carbon Tetrachloride Ammonia	<background[3] <1.0 <2.0	N/A 2.0 25.0
05/17/91	207A Water sample preparation	Volatile Organic Compounds	<background	N/A
05/19/91	207B Water sample preparation	Volatile Organic Compounds	< background	N/A
05/22/91	207C Water sample preparation	Volatile Organic Compounds Carbon Tetrachloride Ammonia	< background < 1.0 < 2.0	N/A 2.0 25.0
05/22/91	207C Water and sludge collection on boat	Volatile Organic Compounds	< background	N/A

[1] = Real-time monitoring was not performed July 15-18, 1991, since sample preparation was performed on the boat

[2] = Standard refers to the most stringent standard published by Occupational Safety and Health Administration (OSHA) or American Conference of Governmental Industrial Hygienists (ACGIH)

[3] = Background levels before activities began ranged from 0.0 - 4.0 ppm

N/A = Not applicable. No standard exists for general volatile organic compounds. A stop work level of 1.0 ppm above background levels in the breathing zone was established

ppm = Parts per million

APPENDIX C

APPENDIX C

EVALUATION OF POTENTIAL EXPOSURES FROM VOLATILE ORGANIC COMPOUNDS IN SOILS AT OU4 SOLAR PONDS AREA

A screening evaluation was performed to determine if the low concentrations of volatile organic compounds (VOCs) detected in soils and pond sediment in the Solar Ponds area were likely to contribute significantly to site risks. The objective of this screening level evaluation was to determine the logic of including (or excluding) exposure pathways to VOCs in the exposure assessment for OU4. Based on the rationale described in this Appendix, it is proposed that exposure to VOCs not be quantitatively evaluated in the exposure assessment unless the results of the Phase I RFI/RI sampling and analyses indicate that significant VOC levels exist in the OU4 soil and pond sediment.

Existing data for volatile organic compounds detected in soils and pond sludges from the Solar Ponds area were evaluated for potential exposures to current site workers. As summarized in the Work Plan for OU4 (DOE 1991b), soil samples contained low concentrations of methylene chloride, chloroform, acetone, 2-butanone, 1,1-dichloroethane, 1,1,1-trichloroethane, trichloroethylene, toluene, and xylenes. The results of previous sampling and analyses indicated that the VOCs were estimated concentrations, below the detection limit, and/or were also present in the lab blanks. According to the Work Plan, samples of sludge taken from Pond 207 A contained 4 to 4680 $\mu g/kg$ of acetone and non detect to 1200 $\mu g/kg$ tetrachloroethene. Sludge from Pond 207 B South contained 130 $\mu g/kg$ tetrachlorethene.

U.S. EPA's Part B guidelines for developing Preliminary Remedial Goals (PRGs) was employed to estimate the concentrations of VOCs in soils which would be associated with acceptable levels of hazard on risk. Attachment 1 presents the EPA's methodology for calculating these levels. The results of these calculations are presented in Table I. This screening evaluation suggests that the very low concentrations of volatile organic compounds previously detected in soils and pond sludges are unlikely to make a significant contribution to current or future risks.

Appendix C
Table 1 Action Level Concentrations for Chemicals of Potential Concern at Rocky Flats

CHEMICAL	SOIL-TO-AIR VOLATILIZATION FACTOR (M^3/KG)	INHALATION RD (MG/KG/DAY)	INHALATION CSF 1/(MG/KG/DAY)	HAZARD-BASED SOIL CONC (MG/KG)	RISK-BASED SOIL CONC (MG/KG)	INHALATION RISK-BASED SOIL ACTION LEVEL (MG/KG)
Acetone	9044.57	NA	NA	ND	ND	ND
2-Butanone	15562.60	8.57E-02	NA	4669	ND	4668
Carbon Tetrachloride	4327.73	NA	5.25E-02	ND	0.29	0.29
Chloroform	9197.84	NA	8.05E-02	ND	0.40	0.40
1,1-Dichloroethane	2150.71	NA	NA	ND	ND	ND
Ethylbenzene	1641.39	2.86E-01	NA	11653	ND	1653
Methylene chloride	4123.39	8.57E-02	1.65E-03	ND	8.75	9
Methyl isobutyl ketone	34056.41	2.29E-02	NA	2730	ND	2730
1,1,2,2-Tetrachloroethane	34504.32	NA	2.03E-01	ND	0.59	0.59
Tetrachloroethane	8213.71	NA	1.82E-03	ND	16	16
Toluene	11653.13	1.14E-01	NA	ND	ND	ND
1,1,1-Trichloroethane	7183.89	2.86E-01	NA	7191	ND	7191
Trichloroethane	7760.92	NA	6.00E-03	ND	5	5
Xylenes	13932.90	8.57E-02	NA	ND	ND	ND

Table I in Appendix B presents a summary of 236 personal air sampling measurements for volatile organic compounds taken from workers performing water and sludge sampling activities at the Solar Ponds during May and July, 1991. The range of concentrations of each chemical agent detected in personal air in the vicinity of Ponds 207 A-C can be compared to the corresponding 8-Hour Time Weighted Average (TWA) Standard displayed in the third column. Concentrations of chemicals in personal air samples which exceed the TWA concentration would indicate that an exposure exceeding the "acceptable exposure concentration" may have occurred. The highest exposure concentration divided by the chemical specific TWA is called the STD Ratio and is displayed in the second column of the Table. An STD Ratio greater than 1.0 indicates exposure to a concentration of that agent which exceeded the acceptable concentration for occupational inhalation exposure. None of the 236 personal air samples had concentrations of volatile organic compounds which exceeded TWA levels. Most of the volatile organic chemicals for which the personal air samples were analyzed were not present above laboratory detection limits. Non-detects are indicated by a "less than" designation (i.e., <). From an occupational health perspective, these data suggest that, on the days the samples were collected, none of the agents listed in Table I were present in air near the Solar Ponds at concentrations exceeding workplace standards.

Overall, the results of the screening level analysis for determining soil VOC concentrations associated with acceptable hazard and risk, and the evaluation of worker breathing zone VOC concentrations demonstrate that inhalation of VOCs will provide a very minimal contribution to the total exposures to potential OU4 receptors. These data are most applicable to the onsite worker, who would likely be subject to the highest potential exposure (of all the identifiable receptors for OU4) through inhalation of VOCs emissions.

APPENDIX C

TABLE 2 PARAMETER VALUES FOR THE DEVELOPMENT OF SOIL CRITERIA LEVELS FOR INHALATION OF VOCs

hemical	Koc	OC	Pt	Pa	Dei	alpha	LS	V	DH	A	Pi	VF
cetone	0.37	0.02	0.433962	0.283962	0.009951	0.000202	45	2.25	2	20250000	3.14	9044.573
-Butanone	1.23	0.02	0.433962	0.283962	0.006484	0.000069	45	2.25	2	20250000	3.14	15562.60
arbon tetrachloride	70.79	0.02	0.433962	0.283962	0.006259	0.000720	45	2.25	2	20250000	3.14	4327.726
hloroform	43.65	0.02	0.433962	0.283962	0.008346	0.000194	45	2.25	2	20250000	3.14	9197.839
,1-Dichloroethane	14.13	0.02	0.433962	0.283962	0.008346	0.002091	45	2.25	2	20250000	3.14	2150.706
thylbenzene	95.5	0.02	0.433962	0.283962	0.006018	0.000121	45	2.25	2	20250000	3.14	11641.39
lethylene chloride	8.71	0.02	0.433962	0.283962	0.008105	0.000818	45	2.25	2	20250000	3.14	4123.385
lethyl isobutyl ketone	6.17	0.02	0.433962	0.283962	0.006018	0.000014	45	2.25	2	20250000	3.14	34056.40
,1,2,2-Tetrachloroethane	46.03	0.02	0.433962	0.283962	0.005697	0.000014	45	2.25	2	20250000	3.14	34504.32
etrachloroethene	209.89	0.02	0.433962	0.283962	0.005778	0.000234	45	2.25	2	20250000	3.14	8213.707
oluene	114.82	0.02	0.433962	0.283962	0.006981	0.000122	45	2.25	2	20250000	3.14	11653.13
,1,1-Trichloroethane	103.99	0.02	0.433962	0.283962	0.006259	0.000302	45	2.25	2	20250000	3.14	7183.885
richloroethene	64.57	0.02	0.433962	0.283962	0.006339	0.000262	45	2.25	2	20250000	3.14	7760.919
ylenes	128.82	0.02	0.433962	0.283962	0.006981	0.000086	45	2.25	2	20250000	3.14	13932.90

APPENDIX C

TABLE 2 PARAMETER VALUES FOR THE DEVELOPMENT OF SOIL CRITERIA LEVELS FOR INHALATION OF VOCs

Chemical	Theta	beta	Ps	Kas	T	Di	H	Kd
Acetone	0.1	1.5	2.65	0.138513	7.9E+08	0.124	0.000025	0.0074
2-Butanone	0.1	1.5	2.65	0.0725	7.9E+08	0.0808	0.000043	0.0246
Carbon tetrachloride	0.1	1.5	2.65	0.868766	7.9E+08	0.078	0.03	1.4158
Chloroform	0.1	1.5	2.65	0.159209	7.9E+08	0.104	0.00339	0.873
1,1-Dichloroethane	0.1	1.5	2.65	2.234253	7.9E+08	0.104	0.0154	0.2826
Ethylbenzene	0.1	1.5	2.65	0.138240	7.9E+08	0.075	0.00644	1.91
Methylene chloride	0.1	1.5	2.65	0.750803	7.9E+08	0.101	0.00319	0.1742
Methyl isobutyl ketone	0.1	1.5	2.65	0.016446	7.9E+08	0.075	0.000049	0.1234
1,1,2,2-Tetrachloroethane	0.1	1.5	2.65	0.016923	7.9E+08	0.071	0.00038	0.9206
Tetrachloroethene	0.1	1.5	2.65	0.283243	7.9E+08	0.072	0.029	4.1978
Toluene	0.1	1.5	2.65	0.119264	7.9E+08	0.087	0.00668	2.2964
1,1,1-Trichloroethane	0.1	1.5	2.65	0.339071	7.9E+08	0.078	0.0172	2.0798
Trichloroethene	0.1	1.5	2.65	0.288911	7.9E+08	0.079	0.0091	1.2914
Xylenes	0.1	1.5	2.65	0.083865	7.9E+08	0.087	0.00527	2.5764

APPENDIX C

ATTACHMENT 1

Soil-to-Air Volatilization Factor (VF)

The volatilization factor (VF) is used for defining the relationship between the concentration of contaminant in soil and the volatilized contaminant in air. This relationship was established as part of the Hwang and Falco (1986) model developed by EPA's Exposure Assessment Group in the Office of Research and Development. Hwang and Falco present a method intended primarily to estimate the permissible residual levels associated with the cleanup of contaminated soils.

The Hwang and Falco model was used as the basis for the VF equation presented in the Part B guidance. Since the time of Part B, OERR sponsored a study to validate the VF equation by comparing the modelled results with data from actual bench and pilot scale studies. The results of the validation study (EQM, 1992) suggested the need to modify the VF equation in Part B to take into account the decrease in the rate of flux due to the effect of soil moisture on effective diffusivity (D_{ei}). Thus, the D_{ei} equation for dry soil (D_i x $E^{0.33}$) was replaced with an equation from Millington and Quirk (1961) where $D_{ei} = D_i\ (Pa^{3.33}/Pt^2)$.

$$VF\ (m^3/kg) = \frac{(LS \times V \times DH)}{A} \times \frac{(3.14 \times \alpha \times T)^{1/2}}{(2 \times D_{ei} \times P_a \times K_{as} \times 10^{-3}\ kg/mg)}$$

where:

$$\alpha = \frac{D_{ei} \times P_a}{P_a + (\rho_s)\ (1 - P_a)/K_{as}}$$

Parameter	Definition (units)	Default
VF	Volatilization factor (m^3/kg)	--
LS	Length of side of contaminated area (m)	45
V	Windspeed in mixing zone (m/s)	2.25
DH	Diffusion height (m)	2
A	Area of contamination (cm^2)	20,250,000
D_{ei}	Effective diffusivity (cm^2/s)	$D_i(Pa^{3.33}/Pt^2)$
P_a	Air filled soil porosity (unitless)	$P_t - \theta\beta$
P_t	Total soil porosity (unitless)	$1-(\beta/\rho_s)$

θ	Soil moisture content (cm^3-water/g-soil)	10% or 0.1
β	Soil bulk density (g/cm^3)	1.5
ρ_s	True soil density or particle density (g/cm^3)	2.65
K_{as}	Soil-air partition coefficient (g-soil/cm^3-air)	$(H/K_d) \times 41$ (41 is a conversion factor)
T	Exposure interval (s)	7.9×10^8 s
D_i	Diffusivity in air (cm^2/s)	Chemical-specific
H	Henry's Law constant (atm-m^3/mol)	Chemical-specific
K_d	Soil-water partition coefficient (cm^3/kg)	$K_{oc} \times OC$
K_{oc}	Organic carbon partition coefficient (cm^3/kg)	Chemical-specific
OC	Organic carbon content of soil (fraction)	2% or 0.02

Soil Saturation Concentration (C_{sat})

The basic principle of the VF model is applicable only if the soil contaminant concentration is at or below saturation. Saturation is the soil contaminant concentration at which the adsorptive limits of the soil particles and the solubility limits of the available soil moisture have been reached. Above saturation, pure liquid-phase contaminant is expected in the soil. Under such conditions, the partial pressure of the pure contaminant and the partial pressure of the air in the interstitial pore spaces cannot be calculated without first knowing the mole fraction of the contaminant in the soil. Therefore, above saturation the PRG cannot be accurately calculated based on volatilization. Because of this limitation, the chemical concentration in soil (PRG) calculated using VF must be compared with the soil saturation concentration (C_{sat}). If the PRG calculated using VF is greater than C_{sat}, the PRG should be set equal to C_{sat}.

$$C_{sat} = \frac{(K_d \times C_w \times \beta) + (C_w \times P_w) + (C_w \times H' \times P_a)}{\beta}$$

Parameter	Definition (units)	Default
C_{sat}	Soil saturation concentration (mg/kg)	--
K_d	Soil-water partition coefficient (L/kg)	K_{oc} x OC
K_{oc}	Organic carbon partition coefficient (L/kg)	Chemical-specific
OC	Organic carbon content of soil (fraction)	2% or 0.02
C_w	Upper limit of free moisture in soil (mg/L-water)	S x θ_m
θ_m	Soil moisture content (kg-water/kg-soil)	10% or 0.1
S	Solubility in water (mg/L-water)	Chemical-specific fraction .1E6
β	Soil bulk density (kg/L)	1.5
P_w	Water filled soil porosity (unitless)	$P_t - P_a$
H'	Henry's Law constant (unitless)	H x 41, where 41 is a conversion factor
H	Henry's Law constant (atm-m^3/mol)	Chemical-specific
P_a	Air-filled soil porosity (unitless)	$P_t - \theta\beta$
θ	Soil moisture content (L-water/kg soil)	10% or 0.1
P_t	Total soil porosity (unitless)	$1 - (\beta/\rho_s)$
ρ_s	True soil density or particle density (kg/L)	2.65

Please note that the equation presented here for C_{sat} is also a modification of the equation presented in the Part B guidance. This equation also takes into account the amount of contaminant that is in vapor phase in the pore spaces of the soil.